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## EDITORIAL

### Concerning Society Finances

YOUR Editor has been asked to make an announcement through the pages of the *Journal* regarding a change in the collection of dues. Hitherto, dues cards have been mailed by the Treasurer during the month of November, and any delinquents have been carried on the mailing list for the *Journal* until April 1. This procedure has been in force for so long that April 1 has come to be thought of by many as the date on which O.S.A. dues became payable.

Recently, all the Founder Societies of the American Institute of Physics agreed to a change in this procedure. Under the new procedure, dues cards will be mailed by the Treasurer much earlier, probably sometime in September, and it is hoped that every member will plan to remit his dues for the ensuing year promptly. In any case, the *Journal* subscription will be discontinued on January 1 if dues for the forthcoming year have not been paid.

Probably not many members realize the extent to which promptness in the payment of their dues on the first billing contributes to the general welfare of the Society. Stated conversely, those who are sometimes tardy in the payment of their dues probably do not realize how large a fraction of their dues is dissipated by the additional clerical work that their tardiness necessitates. Because the Secretary's office maintains a stencil file, the cost of addressing dues cards to almost two thousand members is almost negligible. However, if a second mailing is necessary, it involves special handling; and, if a member does not pay his dues by the cut-off date, even more special handling is required.

It has always been the aim of the officers of your Society to publish all the worth-while contributions in the field of optics, and the Society can be justly proud of its *Journal*. It is no secret that the cost of nearly everything has doubled in recent years, but, despite this trend and an increase in the amount of material being published, there has been only one small increase in membership dues in recent years. The fact that a member of this Society can receive twelve issues of the *Journal*, notices, and programs of meetings, etc. for less than the price of one package of cigarettes per week (this is the Secretary's idea of economy on the barter system, the Editor would prefer a strawberry sundae) is indicative of considerable efficiency in the manifold operations of the Society. Some of the costs in connection with publication of the *Journal* are still rising, but, if every member will cooperate by remitting his dues promptly on receipt of the first notice, the saving in clerical expenses should more than offset the increased expenses. In that case, no increase in dues will be necessary.

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 40, NUMBER 9 SEPTEMBER, 1950

# The Arc and Spark Spectra of Gadolinium

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Analyses based on wave-numbers and intensities have led to the classification of 1177 lines of Gd II, and 1217 of Gd I. The percentages of the stronger lines which have been classified are respectively 77 and 90; of all lines 45 and 40. Almost all lines of astrophysical interest are included.

All the identifiable terms are derived from the ground-state $^9S^\circ$ of the triply ionized atom. A complete analysis will probably be very difficult. The multiplets are remarkably regular for so high an atomic number. Intercombinations are numerous and strong, and often occur between terms differing widely in multiplicity and type. Terms of multiplicity 11 are present in Gd I and account for some of the strongest lines.

## 1. INTRODUCTION

HUND'S classical theory[1] (1927) predicts that the highest multiplicity occurring in the arc spectrum of any element should be 11, in Gd I, and that the whole number of terms should be very great. The first recognition of actual structure, by Albertson[2] identified the ground term, $^9D^\circ$, and thirty levels combining with it. W. A. Albertson, who was deeply engaged in other researches, generously offered to turn over the study of Gd I to the writer, who, some time later succeeded in finding a few terms of multiplicity 11.[3]

The first identification of terms in Gd II was also made by Albertson, Bruynes, and Hanau[4] who identified the lowest term, $^{10}D^\circ$, and a few other levels. Study of this spectrum also was kindly passed on to the writer.

The present investigation is based upon the measures of A. S. King,[5] which were kindly supplied by him some time in advance of publication. With their aid, and Albertson's data as a start, there was no great difficulty in extending the analysis, though no further Zeeman data were available.

Almost 2400 lines—divided almost equally between Gd I and Gd II and including forty percent of all the observed lines, and a much larger proportion of the strong ones—had been classified when the writer's work was interrupted in 1943 by serious illness; and various circumstances have interfered with its resumption.

A survey of the situation indicates that study based on frequency-differences, intensities, and temperature classes has reached the point of seriously diminishing returns, although many strong lines of Gd II remain unclassified. Observations of the Zeeman effect may permit a considerable extension; but these are not available. The writer deems it wise, therefore, to publish the results so far obtained, leaving further analysis to others.

Lists of classified lines of wave-length exceeding 3000A may be found in Miss Moore's "Revised Multiplet Table."[6] These are extensive for Gd II, but very limited for Gd I. The general spectroscopic discussion appears here for the first time.

## 2. THE OBSERVATIONS

King's list is based upon exhaustive observations, with unusually pure material, in the furnace, arc, and spark. It gives wave-lengths, intensities and temperature classes for 5775 lines between 2135A and 10677A, and includes a great number not previously recorded. A search for lines predicted by the writer's analysis, which A. S. King very kindly made, added only three very faint ones, all of Gd II. He lists 53 blends of arc and spark lines and one of arc lines of different temperature classes, so that the whole number of lines to be accounted for is 5832. The intensities are estimated on a very open scale, from 10,000 to 1—a great improvement upon the old compressed scale.

Lines of Gd I, Gd II, and a group of higher excitation attributed to Gd III, are separated according to their behavior in the various sources. The list contains only lines measured in the arc—omitting many strong ones which appear in the spark alone. King records 2786 spark lines (including components of blends). Adding the three lines found by prediction gives 2789. The remaining lines may be attributed to Gd I. Of the enhanced lines, he assigns 116 to Gd III, and 93 others are called by him E? "usually because in the spark spectrum the line is masked by a line probably belonging to Gd III." Assuming that half of these are due to Gd III, the distribution of King's lines (counting blends twice) may be estimated as 162 of Gd III, 2627 of Gd II and 3043 of Gd I. Inclusion of the lines confined to the spark would increase the first number greatly, and the second perhaps considerably, as lines arising from high levels in Gd II may not appear in the arc.

The separation has been remarkably successful. In King's final list 115 lines were marked E (enhanced) which were not so recorded in the preliminary list furnished by him two years before. All but one of these

[1] F. Hund, *Linienspektren und periodisches System der Elemente* (Verlag Julius Springer, Berlin, 1927), p. 176.
[2] W. Albertson, Phys. Rev. **47**, 370 (1935).
[3] H. N. Russell, Astrophys. J. **96**, 11 (1942).
[4] W. E. Albertson, H. Bruynes, and R. Hanau, Phys. Rev. **57**, 292 (1940).
[5] A. S. King, Astrophys. J. **97**, 323 (1943).
[6] C. E. Moore, Contr. Princeton Univ. Obs., No. 20, pp. 92–95 (1945).

were assigned by the analysis to Gd II, but of the 116 which King assigned to Gd III, only one agreed with a prediction for Gd II.

### 3. SPECTRAL STRUCTURES TO BE ANTICIPATED

According to Hund's theory, the principal low terms in Gd III should come from the configurations $4f^7\,5d$ and $4f^7\,6s$; in Gd II from $4f^7\,5d^2$, $4f^7\,5d\,6s$ and $4f^7\,6s^2$; and in Gd I from $4f^7\,5d\,6s^2$ and $4f^7\,5d^2\,6s$. All will be of odd parity. Even configurations, involving $4f^8$ and perhaps $4f^6$, will lie higher.

The $f^7$ configuration alone gives rise theoretically to 119 terms containing 327 energy levels. If any considerable fraction of these terms were almost equally low, the spectra would be excessively complex. But a half-shell of electrons always gives one level which is much lower than the rest. For $f^7$ this is $^8S°$. The terms derived from this may be expected to dominate the spectrum.

For Gd III the addition of $6s$ to $^8S°$ gives $^9S°$, $^7S°$; of $5d$, $^9D°$, $^7D°$; and of $6p$, $^9P$, $^7P$—in all 12 odd levels combining with 6 higher even ones. For Gd II, adding $6s^2$ gives $^8S°$; $6s\,5d$, $^{10}D°$, $^8D°$, $^8D°$, $^6D°$; and $5d^2$, $^{10}F°$, $^{10}P°$; $^8G°$, $^8F°$, $^8D°$, $^8P°$, $^8S°$; $^6F°$, $^6P°$; also $6s\,6p$ gives $^{10}P$, $^8P$, $^8P$, $^6P$; and $5d\,6p$, $^{10}PDF$, $^8PDF$, $^8PDF$, $^6PDF$; —in all, 64 odd levels combining with 71 even ones.

A similar calculation for Gd I gives a total of 96 odd levels arising from $5d\,6s^2$ and $5d^2\,6s$, and of 376 even levels from $6s^2\,6p$, $6s\,5d\,6p$ and $5d^2\,6p$.

The part of the spectrum under consideration should consist, in Gd III, of a few strong lines (44 at most, including intersystem combinations) in Gd II, of several hundred lines, and in Gd I of many thousand, if all the combinations were of perceptible intensity.

The lines which King ascribes to Gd III are all weak, except for ten lying between 2550A and 2720A, with intensities between 100 and 500. The wave numbers of these, and of fainter neighboring lines of the same type, have been examined for constant differences, with no conclusive result. Some of the fundamental lines of Gd III may be among them; the majority evidently are beyond the limit of King's measures.

An investigation of this spectrum, based on measures including spark lines, and extending to shorter wavelengths, would be highly repaying, especially if accompanied by observations of Zeeman effect.

TABLE I. Mean intensity of two strongest lines in each multiplet.

| Config | $4f^7\,6s^2$ | $4f^7\,6s\,5d$ | | | | $4f^7\,5d^2$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Term | $a\,^8S°$ | $a\,^{10}D°$ | $a\,^8D°$ | $b\,^8D°$ | $a\,^6D°$ | $a\,^{10}F°$ | $a\,^{10}P°$ | $a\,^8G°$ | $a\,^8F°$ | $c\,^8D°$ |
| $z\,^{10}P$ | 170 | 1750 | 400 | 600 | 2 | 400 | 2700 | I | 40 | —* |
| $y\,^{10}P$ | 350 | 10000 | 1000 | 10 | — | 80 | 400 | 4 | 40 | 60 |
| $z\,^{10}D$ | 20 | 8000 | 1000 | 500 | 160 | 3000 | 600 | 2* | 450 | 9* |
| $z\,^{10}F$ | 450 | 6500 | 2000 | 800 | — | 1000 | 150 | I | 500 | 8 |
| $z\,^8P$ | 600 | 1500 | 400 | 160 | 50 | 900 | 300 | —* | 130 | —* |
| $y\,^8P$ | 4000 | 1500 | 1800 | 150 | 45 | 60 | 50 | 20 | 320 | 400 |
| $x\,^8P$ | 3200 | 70 | 5000 | 600 | 300 | 300 | 20 | 18 | 5 | 25 |
| $w\,^8P$ | 4000 | U | 3500 | 3500 | 100 | 75 | 180 | 35 | 10 | 250 |
| $z\,^8D$ | 150 | 9000 | 2500 | 600 | 80 | 1600 | 100 | 20* | 650 | 30 |
| $y\,^8D$ | 400 | 200 | 700 | 300 | 175 | 140 | 20 | 90 | 300 | 18 |
| $z\,^8F$ | 250 | 2500 | 4500 | 275 | 50 | 400 | 20 | 1500 | 550 | 90 |
| $y\,^8F$ | 25 | 100 | 60 | 1000 | 300 | 15 | 45 | 175 | 60 | 50 |
| $z\,^6P$ | 400 | 150 | 120 | 40 | 250 | — | — | 4 | 3 | 3 |
| $y\,^6P$ | 600 | — | 550 | 100 | 700 | 6 | 8 | — | 5 | — |
| $z\,^6D$ | 750 | — | 2400 | 600 | 1000 | 400 | 1 | 8 | 2 | 15 |
| $z\,^6F$ | 400 | 15 | 1000 | 700 | 400 | 80 | 8 | 200 | 40 | 60 |

U Inaccessible in ultraviolet. I Inaccessible in infra-red. * Near limit of observation in the red.

TABLE II. Numbers of identified and unidentified lines of Gd II.

| Lines | Intensity >1000 | 1000 to 100 | <100 | All |
|---|---|---|---|---|
| In multiplets | 123 | 347 | 556 | 1026 |
| Not in multiplets | 4 | 29 | 118 | 151 |
| Unidentified | 8 | 138 | 1304 | 1450 |
| All | 135 | 514 | 1978 | 2627 |
| Percent identified | 94 | 73 | 34 | 45 |

TABLE III. Low terms of Gd I and Gd II.

| Gd II | | | | Gd I | | | |
|---|---|---|---|---|---|---|---|
| Conf $4f^7\,6s^2$ | Term $a\,^8S°$ | Level 3444 | Sep — | Conf None | Term — | Level — | Sep — |
| $4f^7\,6s\,5d$ | $a\,^{10}D°$ | 633 | 1935 | $4f^7\,6s^2\,5d$ | | | |
| | | | | | $a\,^9D°$ | 533 | 1719 |
| | $a\,^8D°$ | 3427 | 1984 | | | | |
| | $b\,^8D°$ | 9143 | −901 | | | | |
| | | | | | $a\,^7D°$ | 7427 | −677 |
| | $a\,^6D°$ | 10633 | −817 | | | | |
| $4f^7\,5d^2$ | | | | $4f^7\,6s\,5d^2$ | $a\,^{11}F°$ | 7103 | 2120 |
| | $a\,^{10}F°$ | 4852 | 2578 | | | | |
| | | | | | $a\,^9F°$ | 10884 | 2264 |

### 4. THE FIRST SPARK SPECTRUM, Gd II

In this spectrum, analysis based on frequency differences and intensities has led to the recognition of 55 odd and 82 even levels, whose combinations account for 1177 observed lines.

The odd levels so far detected lie lower than any of the even ones. All but four of them may be placed without constraint in terms arising from $4f^7(^8S°)$ through the configurations $4f^7\,6s^2$, $4f^7\,6s\,5d$, and $4f^7\,5d^2$. The arrangement of these terms and the intervals of their components are remarkably regular for so heavy an atom, and there is little or no uncertainty about their assignment.

The lowest terms, $a\,^{10}D°$, $a\,^8D°$, come from $4f^7\,6s\,5d$. The latter overlaps $a\,^8S°(4f^7\,6s^2)$ and $a\,^{10}F°(4f^7\,5d^2)$. Next follow $b\,^8D°$, $a\,^6D°$ from $4f^7\,6s\,5d$. The order of components in these two terms is "inverted," as in the corresponding terms in the isoelectronic spectrum Eu I.[7] The higher terms, $a\,^{10}P°$, $a\,^8F°$, $c\,^8D°$, $a\,^8G°$, come from $4f^7\,5d^2$. Four predicted terms from this configuration ($^6F°$, $^6P°$, $^8P°$, and $^8S°$) have not been identified. They include thirteen levels in all, and should be as high as, or higher than, the highest recognized terms. The four unclassified levels may be parts of these.

The configuration $4f^7\,6s\,6p$ gives the even terms

[7] H. N. Russell and A. S. King, Astrophys. J. **90**, 155 (1939).

TABLE IV. Gd I. Mean intensity of two strongest lines in multiplets.

| | $4f^7\,5d\,6s^2$ | | $4f^7\,5d^2\,6s$ | | $4f^7\,5d\,6s\,7s$ | | $4f^7\,6s^2\,7s$ |
|---|---|---|---|---|---|---|---|
| | $a\,^9D°$ | $a\,^7D°$ | $a\,^{11}F°$ | $a\,^9F°$ | $e\,^{11}D°$ | $e\,^9D°$ | $e\,^9S°$ |
| $z\,^{11}F$ | 1750 | I | 20* | I | 500 | 12 | 10 |
| $z\,^{11}D$ | 130 | I | 175* | I | 400 | 8 | 30 |
| $z\,^{11}P$ | 300 | 25 | 65* | I | 30 | 17 | 50 |
| $z\,^{11}G$ | 800 | 120 | 4000 | 10 | I | I | I |
| $y\,^{11}F$ | 75 | 25 | 900 | 250 | I | I | I |
| $y\,^{11}D$ | 100 | 30 | 450 | 20 | I | I | I |
| $z\,^9P$ | 2200 | I | I | I | 18 | 14 | 140 |
| $y\,^9P$ | 250 | 60 | — | 1* | — | 10 | — |
| $x\,^9P$ | 1300 | 40 | 15 | — | I | I | I |
| $z\,^9D$ | 600 | 10 | 22 | 150 | I | 10* | — |
| $y\,^9D$ | 2800 | 40 | 200 | 225 | I | I | I |
| $x\,^9D$ | 200 | 100 | 6 | 175 | I | I | I |
| $z\,^9F$ | 7000 | I | 40* | I | 30 | 175 | — |
| $y\,^9F$ | 2500 | 35 | 200 | 200 | I | I | I |
| $x\,^9F$ | 1200 | 200 | 150 | 35 | I | I | I |
| $w\,^9F$ | 1500 | 40 | 25 | 600 | I | I | I |
| $z\,^9G$ | 40 | 3 | 70 | 3500 | I | I | I |
| $x\,^7P$ | 40 | 100 | 12 | 12 | I | I | I |
| $z\,^7D$ | 400 | 1000 | 5 | I | — | 4 | — |
| $x\,^7D$ | 140 | 650 | 30 | 80 | I | I | I |
| $x\,^7F$ | 45 | 700 | 10 | 30 | I | I | I |

I In infra-red. * Near limit of observation in red.

$^{10}$P, $^8$P, $^8$P, $^6$P; and $4f^7\,5d\,6p$ gives $^{10}$PDF, $^8$PDF, $^8$PDF, $^6$PDF. The 71 components of these 16 terms have all been identified among the observed even levels.

A careful re-examination of intervals and multiplet intensities indicates that the term-designations made in 1943, and used in the Revised Multiplet Table, though doubtful in a few cases, can hardly be improved until observations of the Zeeman effect are available. They are therefore given here without any change.

(For future reference, it may however be noted that an improvement in the multiplet intensities would result from interchanging the designations $x\,^8P_{4\frac{1}{2}}$ and $z\,^6D_{4\frac{1}{2}}$ and that the multiplets involving $y\,^8P$ show abnormal intensities.)

5

Intercombinations between terms of different names, multiplicities, and configurations are very strong. Table I gives the average intensity of the two strongest lines in the multiplet arising from each pair of terms.

Of 157 predicted multiplets in the observed region, 146 are present. Some contain only a few faint lines, but it is evident that the usual restrictions are greatly relaxed, and that there is extensive "sharing" of th classical properties of the levels.

This makes it difficult to decide which of the P-terms in Table I belong to $4f^7\,6s\,6p$ and which to $4f^7\,5d\,6p$, and this has not been attempted. All the D- and F-terms come from the latter.

6

The analysis of Gd II is far advanced, though incomplete, as regards the part arising from $4f^7(^8S°)$ in Gd IV. All the even terms have been found, and the unidentified odd terms are likely to give relatively faint multiplets.

Almost all of the strongest lines, and a large majority of those of moderate intensity, are thus accounted for—as shown in Table II.

A great majority of the unidentified lines must arise from transitions involving configurations not yet identified. There are many possibilities—odd terms from $4f^7\,6s^2$, $4f^7\,6s\,5d$, $4f^7\,5d^2$ and even ones from $4f^7\,6s\,6p$, $4f^7\,5d\,6p$, with any term of $4f^7$ except $^8S°$ as limit; odd terms from $4f^8\,6p$ and even ones from $4f^8\,6s$ and $4f^8\,5d$, and still others. Eleven of the known even levels (though not necessarily those to which numbers have been assigned in Table VII) must come from some of these configurations.

The number of possible terms is very great, and it is probable that only the strongest lines of the multiplets are observable. This may make analysis by means of frequency differences almost impossible, as in Sm I.[8]

Considerable time spent in searching for new clues has been unrewarded, and it has therefore been decided to close the present investigation. Even when good observations of the Zeeman effect become available, there is likely to be an intractable residue of lines which cannot be placed, as in Eu II.[9]

7

The ionization potential of Gd II can be determined when terms arising from configurations including a 7*s*-electron are found. The lowest terms of Gd III are undoubtedly $4f^7\,5d\,^9D°$, $^7D°$, with the latter inverted and lying considerably the higher, as in Eu II. The lowest terms from $4f^7\,5d\,7s$ will then be $^{10}D°$, $^8D°$—in series with $a\,^{10}D°$, $a\,^8D°$, and combining strongly with the triads $z\,^{10}F$, $z\,^{10}D$, $y\,^{10}P$, etc.

A careful search, using the differences of the leading components of these triads, led to no result.

This indicates that the lines in question, which arise from high levels in the ionized atom, are very faint or absent in the arc. The corresponding lines could not be found in Sm II,[10] despite careful search, though they are conspicuous in Eu II. When the lines which appear only in the spark have been measured, it is probable that these combinations will be found, and possible that they may be conspicuous. Meanwhile it may be estimated that the ionization potential of Gd II is a little greater than that of Eu II,—that is, 12 to 13 volts.

### 8. THE ARC SPECTRUM, Gd I

The lowest term of Gd I, $a\,^9D°$, was found by Albertson. With this start, three other low terms were easily found. These terms are obtained by adding a 6*s*-electron

[8] W. Albertson, Phys. Rev. **52**, 644 (1937).
[9] H. N. Russell, W. Albertson, and D. N. Davis, Phys. Rev. **60**, 641 (1941).
[10] W. Albertson, Astrophys. J. **84**, 26 (1936).

to the low terms of Gd II, and Pauli's restriction limits their number, as shown in Table III. The middle level of each term, and its over-all separation, are given. The relations of these terms are now clear.

No low levels except the 24 members of the terms given in Table III have been detected, despite careful search. The terms resulting from adding a 6*s*-electron to *a* $^{10}$P° and *a* $^{8}$F° of Gd II should be below 20000. Analogy with other arc spectra with three "running" electrons indicates that the terms from $4f^7\,5d^3$ should be much higher.

Some 200 even levels have been identified—largely because their combinations with *a* $^{9}$D° are conspicuous in the furnace. Among them 21 terms, containing 118 levels, have been identified—some provisionally. The standards of acceptance tend to be conservative. There remain 85 unassigned levels.

Three high odd terms, including 11 levels, and arising from the addition of a 7*s*-electron to *a* $^{10}$D°, *a* $^{8}$S°, were found in 1942, before much other progress had been made in the analysis. They and the related multiplets have been described in detail.[3]

Rydberg formulas, assuming the differences of the denominators to be the same as for Eu I, placed *a* $^{10}$D°$_{2\frac{1}{2}}$ 49700 cm$^{-1}$ above *a* $^{9}$D°$_2$, making the ionization potential 6.16 volts. The prediction that *a* $^{8}$S° (then unknown) should be near 3810 was only 370 cm$^{-1}$ in error.

9

The mean intensity of the two strongest lines (omitting blends), in each multiplet resulting from the adopted terms is given in Table IV. Strong intercombinations are again conspicuous.

The addition of a 6*p*-electron to the limit-terms listed in Table III should produce a total of 32 terms containing 166 levels. These, and the combining properties which would normally be expected from them, are as follows:

*Limit a* $^{8}$S°—$^{9}$P, $^{7}$P, combining more strongly with terms from $6s^2\,5d$ than from $6s\,5d^2$, and probably at a low level.

*Limits a* $^{10}$D°, *a* $^{8}$D°—Four triads, $^{11}$PDF, $^{9}$PDF, $^{7}$PDF, $^{9}$PDF, in this order, with positive separations, combining strongly with *a* $^{9}$D°.

*Limits b* $^{8}$D°, *a* $^{6}$D°—Triads $^{9}$PDF, $^{7}$PDF, $^{5}$PDF, $^{7}$PDF, with negative or small separations and combining strongly with *a* $^{7}$D°.

*Limit a* $^{10}$F°—Triads $^{11}$DFG, $^{9}$DFG, combining strongly with *a* $^{11}$F°, *a* $^{9}$F°.

These may be immediately identified as *y* $^{11}$D, *y* $^{11}$F, *z* $^{11}$G and *x* $^{9}$D, *w* $^{9}$F, *z* $^{9}$G. The combinations of *z* $^{11}$P, *z* $^{11}$D, *z* $^{11}$F with *e* $^{11}$D° show that their limit is *a* $^{10}$D°. Those with *e* $^{9}$D° assign *z* $^{9}$F to the related triad, the other members being probably *z* $^{9}$D and *y* $^{9}$P. The low level of *z* $^{9}$P and its strong combination with *e* $^{9}$S° assign it to *a* $^{8}$S° as limit. (The related low $^{7}$P term has not been fully identified, though the nature and strength of its combinations suggest that the level at 18509 is $^{7}$P$_4$.) Finally, the triad of inverted terms *x* $^{7}$P, *x* $^{7}$D, *x* $^{7}$F may be attributed to one of the inverted limits *b* $^{8}$D°, *a* $^{6}$D°.*

TABLE V. Numbers of identified and unidentified lines of Gd I.

| Lines | Intensity >1000 | 1000 to 100 | <100 | All |
|---|---|---|---|---|
| In multiplets | 62 | 229 | 473 | 764 |
| Not in multiplets | 2 | 83 | 368 | 453 |
| Unidentified | 1 | 41 | 1784 | 1826 |
| All | 65 | 353 | 2625 | 3043 |
| Percent identified | 98 | 88 | 32 | 40 |

The mutual perturbations between many of the other levels are such that it is not always clear to what limit-term they should be assigned—or even to what configuration; and no further assignments have been made.

It is certain, however, that other configurations than those with the limits given in Table III must be present among the unclassified even levels. Of the 49 predicted but unobserved levels, nine have $J=0$ or 1, while of the 85 observed and unassigned levels, two at most can have $J<2$; hence at least 43 of them must come from other limits. The number of possibilities is very great.

10

The present state of classification of Gd I is illustrated in Table V, which is similar to Table II.

The percentage of strong lines identified is greater than in Gd II, and of weak lines less. Allowance for the fact that many lines of Gd II probably fail to appear in the arc would diminish this difference.

The arc and spark spectra of gadolinium belong to the group described by Albertson,[10] in which a comparatively simple spectrum, arising from an isolated low term of the $4f^n$ configuration, and containing almost all of the strong lines and of those of easy excitation, is superposed upon a complex group arising from other limit terms.

As in other cases where a detailed analysis has been made, the simple part has been rather completely analyzed, while the complex portion has effectively defied analysis. All but a few of the lines of astrophysical importance have been classified; and further study is left to younger investigators.

11

The results of the present study are contained in four tables. Table VI gives the adopted terms and also the unclassified energy levels, and Table VII the identified lines, for Gd II; and Tables VIII and IX give similar data for Gd I.

The terms and unclassified levels in Tables VI and

* These are denoted by the prefix *x*, because it appears, from the general structure of the spectrum, that there must be two other terms of the same type at lower levels.

TABLE VI. Terms and levels of Gd II.

| Config. | Desig. | Level | Interval | Config. | Desig. | Level | Interval |
|---|---|---|---|---|---|---|---|
| $4f^7\ 6s\ 5d$ | $a\ ^9D^\circ_{4\frac{1}{2}}$ | 10091.59 | | $4f^7\ 5d^2$ | $a\ ^{10}F^\circ_{7\frac{1}{2}}$ | 6605.20 | |
| | $a\ ^9D^\circ_{3\frac{1}{2}}$ | 10391.80 | −300.21 | | $a\ ^{10}F^\circ_{6\frac{1}{2}}$ | 5897.30 | 707.90 |
| | $a\ ^9D^\circ_{2\frac{1}{2}}$ | 10633.10 | −241.30 | | $a\ ^{10}F^\circ_{5\frac{1}{2}}$ | 5339.52 | 557.78 |
| | $a\ ^9D^\circ_{1\frac{1}{2}}$ | 10802.65 | −169.55 | | $a\ ^{10}F^\circ_{4\frac{1}{2}}$ | 4852.35 | 487.17 |
| | $a\ ^9D^\circ_{\frac{1}{2}}$ | 10908.27 | −105.62 | | $a\ ^{10}F^\circ_{3\frac{1}{2}}$ | 4483.89 | 368.46 |
| | | | | | $a\ ^{10}F^\circ_{2\frac{1}{2}}$ | 4212.81 | 271.08 |
| $4f^7\ 6s^2$ | $a\ ^8S^\circ_{3\frac{1}{2}}$ | 3444.24 | | | $a\ ^{10}F^\circ_{1\frac{1}{2}}$ | 4027.22 | 185.59 |
| $4f^7\ 6s\ 5d$ | $a\ ^8D^\circ_{5\frac{1}{2}}$ | 4841.07 | | | $1^\circ_{2\frac{1}{2}}$ | 18244.80 | |
| | $a\ ^8D^\circ_{4\frac{1}{2}}$ | 3972.15 | 868.92 | | $2^\circ_{2\frac{1}{2}}$ | 18955.11 | |
| | $a\ ^8D^\circ_{3\frac{1}{2}}$ | 3427.24 | 544.91 | | $3^\circ_{4\frac{1}{2}}$ | 19402.08 | |
| | $a\ ^8D^\circ_{2\frac{1}{2}}$ | 3082.01 | 345.23 | | $4^\circ_{4\frac{1}{2}}$ | 19946.91 | |
| | $a\ ^8D^\circ_{1\frac{1}{2}}$ | 2856.67 | 225.34 | | | | |
| | | | | | $z\ ^6P_{3\frac{1}{2}}$ | 31908.16 | |
| $4f^7\ 6s\ 5d$ | $b\ ^8D^\circ_{5\frac{1}{2}}$ | 8551.08 | | | $z\ ^6P_{2\frac{1}{2}}$ | 32750.45 | −842.29 |
| | $b\ ^8D^\circ_{4\frac{1}{2}}$ | 8884.84 | −333.76 | | $z\ ^6P_{1\frac{1}{2}}$ | 33181.65 | −431.20 |
| | $b\ ^8D^\circ_{3\frac{1}{2}}$ | 9142.94 | −258.10 | | | | |
| | $b\ ^8D^\circ_{2\frac{1}{2}}$ | 9328.91 | −185.97 | | $y\ ^6P_{3\frac{1}{2}}$ | 42628.24 | |
| | $b\ ^8D^\circ_{1\frac{1}{2}}$ | 9451.75 | −122.84 | | $y\ ^6P_{2\frac{1}{2}}$ | 42745.38 | −117.14 |
| | | | | | $y\ ^6P_{1\frac{1}{2}}$ | 42964.63 | −219.25 |
| $4f^7\ 5d^2$ | $c\ ^8D^\circ_{5\frac{1}{2}}$ | 17725.14 | | | | | |
| | $c\ ^8D^\circ_{4\frac{1}{2}}$ | 17817.22 | − 92.08 | $4f^7\ 5d\ 6p$ | $z\ ^6D_{4\frac{1}{2}}$ | 39537.20 | |
| | $c\ ^8D^\circ_{3\frac{1}{2}}$ | 17869.98 | − 52.76 | | $z\ ^6D_{3\frac{1}{2}}$ | 39777.32 | −240.12 |
| | $c\ ^8D^\circ_{2\frac{1}{2}}$ | 17971.71 | −101.73 | | $z\ ^6D_{2\frac{1}{2}}$ | 39971.25 | −193.93 |
| | $c\ ^8D^\circ_{1\frac{1}{2}}$ | 18369.41 | −397.70 | | $z\ ^6D_{1\frac{1}{2}}$ | 40091.67 | −120.42 |
| | | | | | $z\ ^6D_{\frac{1}{2}}$ | 40162.45 | − 70.78 |

VIII are arranged as for Fe I.[11] The odd terms are given first, since they include the ground state. Those of each multiplicity (beginning with the smallest observed) are arranged in order of term-types (S, P, D . . .), and the terms of each type in order of level. The unclassified levels, if any, appear at the end. The even terms and levels follow in the same manner.

This arrangement has been adopted, not from any assumption of its superiority to that in which all the terms are given in numerical order, but because the latter method will be employed when, in due course, these spectra are included in the general compilation of *Atomic Energy Levels*.[12] Each method of tabulation has advantages over the other, according to the standpoint of the consultant, and both will thus soon be available.

The common custom of designating the unclassified levels by arbitrary numbers; 1, 2, . . .; 1°, 2°, . . ., in order of their position has been followed, since, after long consideration, no preferable alternative appeared.

The first column gives the electron configuration, whenever an assignment appears practicable. All these configurations are based on the $^8S^\circ$ term from $4f^7$—as explained in § 3. Then follow the designation, the numerical value for each individual level, and the intervals between the components of a term—which are tabulated in order of diminishing inner-quantum numbers.

Tables VII and IX give all the lines which have been identified in the corresponding spectrum. The first column gives the wave-lengths according to King; the next two, the intensities assigned by him in the arc and furnace; and the fourth, his temperature classes. The fifth column gives the wave number corresponding to the observed wave-length; the sixth, the last three figures of that computed from the term-values; and the last, the designation. In a few cases where the discordance between the observed and computed values appears to be large, in view of the accuracy of observation for a line of the given sort, the designation is marked with a "?" or enclosed in parentheses. This is also done when the temperature class of the observed line is discordant, and for lines masked by stronger neighbors. When it is probable that both lines make considerable contributions to a blend, the designations are connected by a bracket.

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In conclusion, it is a pleasure to express the writer's gratitude to Walter Albertson for his generosity in turning over to him the investigation of these very interesting spectra; to A. S. King for the communication of his observations long before their publication; to W. F. Meggers for stimulating the publication of these results through cordial cooperation with the Spectroscopy Section of the National Bureau of Standards; to Mrs. Jay Murray for careful preparation of the manuscript and tables; and above all to Charlotte Moore Sitterly for her generous and unfailing help in supervising this work, and giving it, at all points, the benefit of her unrivaled judgment, accuracy, and skill.

[11] H. N. Russell and C. E. Moore, Trans. Am. Phil. Soc. 34, 111, Table A (1944).

[12] C. E. Moore, *Atomic Energy Levels*, Vol. 1, Circ. Nat. Bur. Stand. 467 (U. S. Government Printing Office, Washington, D. C., 1949). (Further volumes are to follow.)

TABLE VI.—*Continued.*

| Config. | Desig. | Level | Interval |
|---|---|---|---|
| $4f^7\ 5d^2$ | $a\ ^8F^\circ_{6\frac{1}{2}}$ | 13925.81 | |
| | $a\ ^8F^\circ_{5\frac{1}{2}}$ | 13378.05 | 547.76 |
| | $a\ ^8F^\circ_{4\frac{1}{2}}$ | 13076.15 | 301.90 |
| | $a\ ^8F^\circ_{3\frac{1}{2}}$ | 12891.78 | 184.37 |
| | $a\ ^8F^\circ_{2\frac{1}{2}}$ | 12776.17 | 115.61 |
| | $a\ ^8F^\circ_{1\frac{1}{2}}$ | 12703.55 | 72.62 |
| | $a\ ^8F^\circ_{\frac{1}{2}}$ | 12662.28 | 41.27 |
| $4f^7\ 5d^2$ | $a\ ^8G^\circ_{7\frac{1}{2}}$ | 18753.11 | |
| | $a\ ^8G^\circ_{6\frac{1}{2}}$ | 18677.03 | 76.08 |
| | $a\ ^8G^\circ_{5\frac{1}{2}}$ | 18641.43 | 35.60 |
| | $a\ ^8G^\circ_{4\frac{1}{2}}$ | 18319.31 | 322.12 |
| | $a\ ^8G^\circ_{3\frac{1}{2}}$ | 18150.70 | 168.61 |
| | $a\ ^8G^\circ_{2\frac{1}{2}}$ | 18095.79 | 54.91 |
| | $a\ ^8G^\circ_{1\frac{1}{2}}$ | 18001.40 | 94.39 |
| | $a\ ^8G^\circ_{\frac{1}{2}}$ | 17987.69 | 13.71 |
| $4f^7\ 5d^2$ | $a\ ^{10}P^\circ_{5\frac{1}{2}}$ | 11492.27 | |
| | $a\ ^{10}P^\circ_{4\frac{1}{2}}$ | 11066.92 | 425.35 |
| | $a\ ^{10}P^\circ_{3\frac{1}{2}}$ | 10599.81 | 467.11 |
| $4f^7\ 6s\ 5d$ | $a\ ^{10}D^\circ_{6\frac{1}{2}}$ | 1935.30 | |
| | $a\ ^{10}D^\circ_{5\frac{1}{2}}$ | 1158.94 | 776.36 |
| | $a\ ^{10}D^\circ_{4\frac{1}{2}}$ | 633.27 | 525.67 |
| | $a\ ^{10}D^\circ_{3\frac{1}{2}}$ | 261.81 | 371.46 |
| | $a\ ^{10}D^\circ_{2\frac{1}{2}}$ | 0.00 | 261.81 |
| $4f^7\ 5d\ 6p$ | $z\ ^8D_{3\frac{1}{2}}$ | 30008.94 | |
| | $z\ ^8D_{2\frac{1}{2}}$ | 29965.81 | 43.13 |
| | $z\ ^8D_{1\frac{1}{2}}$ | 29878.01 | 87.80 |
| $4f^7\ 5d\ 6p$ | $y\ ^8D_{5\frac{1}{2}}$ | 36461.19 | |
| | $y\ ^8D_{4\frac{1}{2}}$ | 36647.28 | −186.09 |
| | $y\ ^8D_{3\frac{1}{2}}$ | 36711.23 | − 63.95 |
| | $y\ ^8D_{2\frac{1}{2}}$ | 36845.40 | −134.17 |
| | $y\ ^8D_{1\frac{1}{2}}$ | 36995.81 | −150.41 |
| $4f^7\ 5d\ 6p$ | $z\ ^8F_{6\frac{1}{2}}$ | 33558.01 | |
| | $z\ ^8F_{5\frac{1}{2}}$ | 32946.24 | 611.77 |
| | $z\ ^8F_{4\frac{1}{2}}$ | 32684.75 | 261.49 |
| | $z\ ^8F_{3\frac{1}{2}}$ | 32490.56 | 194.19 |
| | $z\ ^8F_{2\frac{1}{2}}$ | 32260.16 | 230.40 |
| | $z\ ^8F_{1\frac{1}{2}}$ | 32048.87 | 211.29 |
| | $z\ ^8F_{\frac{1}{2}}$ | 31977.46 | 71.41 |
| $4f^7\ 5d\ 6p$ | $y\ ^8F_{6\frac{1}{2}}$ | 40773.29 | |
| | $y\ ^8F_{5\frac{1}{2}}$ | 40785.22 | − 11.93 |
| | $y\ ^8F_{4\frac{1}{2}}$ | 40924.99 | −139.77 |
| | $y\ ^8F_{3\frac{1}{2}}$ | 41097.23 | −172.24 |
| | $y\ ^8F_{2\frac{1}{2}}$ | 41260.28 | −163.05 |
| | $y\ ^8F_{1\frac{1}{2}}$ | 41391.73 | −131.45 |
| | $y\ ^8F_{\frac{1}{2}}$ | 41475.72 | − 83.99 |
| | $z\ ^{10}P_{5\frac{1}{2}}$ | 28502.33 | |
| | $z\ ^{10}P_{4\frac{1}{2}}$ | 26455.48 | 2046.85 |
| | $z\ ^{10}P_{3\frac{1}{2}}$ | 25668.70 | 786.78 |

| Config. | Desig. | Level | Interval |
|---|---|---|---|
| $4f^7\ 5d\ 6p$ | $z\ ^8F_{5\frac{1}{2}}$ | 38553.24 | |
| | $z\ ^8F_{4\frac{1}{2}}$ | 38029.89 | 523.35 |
| | $z\ ^8F_{3\frac{1}{2}}$ | 38320.25 | −290.36 |
| | $z\ ^8F_{2\frac{1}{2}}$ | 38628.70 | −308.45 |
| | $z\ ^8F_{1\frac{1}{2}}$ | 38828.47 | −199.77 |
| | $z\ ^8F_{\frac{1}{2}}$ | 38934.22 | −105.75 |
| | $z\ ^8P_{4\frac{1}{2}}$ | 30849.67 | |
| | $z\ ^8P_{3\frac{1}{2}}$ | 27988.09 | 2861.58 |
| | $z\ ^8P_{2\frac{1}{2}}$ | 27297.77 | 690.32 |
| | $y\ ^8P_{4\frac{1}{2}}$ | 32304.45 | |
| | $y\ ^8P_{3\frac{1}{2}}$ | 32262.85 | 41.60 |
| | $y\ ^8P_{2\frac{1}{2}}$ | 32150.19 | 112.66 |
| | $x\ ^8P_{4\frac{1}{2}}$ | 39250.79 | |
| | $x\ ^8P_{3\frac{1}{2}}$ | 39170.26 | 80.53 |
| | $x\ ^8P_{2\frac{1}{2}}$ | 39024.53 | 145.73 |
| | $w\ ^8P_{4\frac{1}{2}}$ | 49053.84 | |
| | $w\ ^8P_{3\frac{1}{2}}$ | 49332.27 | −278.43 |
| | $w\ ^8P_{2\frac{1}{2}}$ | 49547.22 | −214.95 |
| $4f^7\ 5d\ 6p$ | $z\ ^8D_{5\frac{1}{2}}$ | 30366.88 | |
| | $z\ ^8D_{4\frac{1}{2}}$ | 30027.41 | 339.47 |
| | | | 18.47 |
| | $y\ ^{10}P_{5\frac{1}{2}}$ | 34178.82 | |
| | $y\ ^{10}P_{4\frac{1}{2}}$ | 33596.09 | 582.73 |
| | $y\ ^{10}P_{3\frac{1}{2}}$ | 33211.52 | 384.57 |
| $4f^7\ 5d\ 6p$ | $z\ ^{10}D_{6\frac{1}{2}}$ | 30996.88 | |
| | $z\ ^{10}D_{5\frac{1}{2}}$ | 30101.40 | 895.48 |
| | $z\ ^{10}D_{4\frac{1}{2}}$ | 29045.32 | 1056.08 |
| | $z\ ^{10}D_{3\frac{1}{2}}$ | 29242.27 | −196.95 |
| | $z\ ^{10}D_{2\frac{1}{2}}$ | 29197.93 | 44.34 |
| $4f^7\ 5d\ 6p$ | $z\ ^{10}F_{7\frac{1}{2}}$ | 31145.68 | |
| | $z\ ^{10}F_{6\frac{1}{2}}$ | 29353.38 | 1792.30 |
| | $z\ ^{10}F_{5\frac{1}{2}}$ | 27864.56 | 1488.82 |
| | $z\ ^{10}F_{4\frac{1}{2}}$ | 27162.27 | 702.29 |
| | $z\ ^{10}F_{3\frac{1}{2}}$ | 26595.25 | 567.02 |
| | $z\ ^{10}F_{2\frac{1}{2}}$ | 26211.96 | 383.29 |
| | $z\ ^{10}F_{1\frac{1}{2}}$ | 25960.14 | 251.82 |
| | $1_{4\frac{1}{2}}$ | 25609.10 | |
| | $2_{4\frac{1}{2}}$ | 26351.80 | |
| | $3_{3\frac{1}{2}}$ | 27417.69 | |
| | $4_{2\frac{1}{2}}$ | 28629.06 | |
| | $5_{4\frac{1}{2}}$ | 35551.67 | |
| | $6_{3\frac{1}{2}}$ | 37733.96 | |
| | $7_{4\frac{1}{2}}$ | 37846.01 | |
| | $8_{4\frac{1}{2}}$ | 38057.97 | |
| | $9_{5\frac{1}{2}}$ | 38509.63 | |
| | $10_{3\frac{1}{2}}$ | 49291.07 | |
| | $11_{2\frac{1}{2}}$ | 49497.96 | |

TABLE VII. Classified lines of Gd II.

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 9004.80 | 2 | — | V E | 11102.15 | 2.14 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^{10}D_{2\frac{1}{2}}$ |
| 8905.26 | 6 | — | V E | 11226.24 | 6.22 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^{10}D_{2\frac{1}{2}}$ |
| 8831.32 | 8 | — | V E | 11320.23 | 0.18 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 8825.25 | 10 | — | V E | 11328.02 | 7.95 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 8750.30 | 6 | — | V E | 11425.04 | 5.05 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 8686.78 | 4? | — | V E | 11508.59 | 8.60 | $c\ {}^8D^o_{1\frac{1}{2}} - z\ {}^8D_{1\frac{1}{2}}$ |
| 8621.02 | 2 | — | V E | 11596.37 | 6.40 | $c\ {}^8D^o_{1\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 8597.35 | 8 | — | V E | 11628.30 | 8.24 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^{10}F_{3\frac{1}{2}}$ |
| 8552.41 | 30 | — | V E | 11689.40 | 9.63 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$? |
| 8552.2 | 10 | — | V E | 11689.69 | 9.85 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$? |
| 8485.04 | 10? | — | V E | 11782.21 | 2.22 | $a\ {}^8G^o_{2\frac{1}{2}} - z\ {}^8D_{1\frac{1}{2}}$ |
| 8461.45 | 4 | — | V E | 11815.06 | 5.11 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 8396.56 | 2 | — | V E | 11906.37 | 6.30 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8D_{1\frac{1}{2}}$ |
| 8335.03 | 4 | — | V E | 11994.26 | 4.10 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 8235.67 | 15 | — | V E | 12138.97 | 8.96 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 8187.70 | 15 | — | V E | 12210.09 | 0.19 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 8117.31 | 20? | — | V E | 12315.97 | 5.94 | $4^o_{4\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 8089.96 | 60 | — | V E | 12357.61 | 7.54 | $4^o_{4\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 7908.06 | 40*d*? | — | V E | 12641.85 | 1.74 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$ |
| 7773.45 | 4 | — | V E | 12860.77 | 0.77 | $3^o_{4\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 7748.37 | 40 | — | V E | 12902.39 | 2.37 | $3^o_{4\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 7576.50 | 3 | — | V | 13195.07 | 5.08 | $2^o_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$? |
| 7541.41 | 10 | — | V E | 13256.47 | 6.59 | $a\ {}^8F^o_{1\frac{1}{2}} - z\ {}^{10}F_{1\frac{1}{2}}$ |
| 7536.79 | 1 | — | V E | 13264.60 | 4.61 | $4^o_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 7526.57 | 15 | — | V E | 13282.61 | 2.67 | $3^o_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 7517.94 | 10? | — | V E | 13297.86 | 7.86 | $a\ {}^8F^o_{\frac{1}{2}} - z\ {}^{10}F_{1\frac{1}{2}}$ |
| 7505.35 | 80 | — | V E | 13320.18 | 0.18 | $a\ {}^8F^o_{1\frac{1}{2}} - z\ {}^{10}F_{2\frac{1}{2}}$ |
| 7440.75 | 10 | — | V E | 13435.81 | 5.79 | $a\ {}^8F^o_{2\frac{1}{2}} - z\ {}^{10}F_{2\frac{1}{2}}$ |
| 7394.90 | 150 | — | V E | 13519.12 | 9.10 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^{10}F_{3\frac{1}{2}}$ |
| 7385.97 | 80 | — | V E | 13535.46 | 5.45 | $2^o_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 7381.22 | 4 | — | V E | 13544.17 | 4.16 | $3^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 7346.55 | 1 | — | V E | 13608.09 | 8.05 | $c\ {}^8D^o_{1\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 7308.28 | {3 2 | — | V E | 13679.38 | 9.46 | $c\ {}^8D^o_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$? |
| 7295.43 | 4 | — | V E | 13703.44 | 3.47 | $a\ {}^8F^o_{2\frac{1}{2}} - z\ {}^{10}F_{2\frac{1}{2}}$ |
| 7252.70 | 400 | — | V E | 13784.18 | 4.22 | $a\ {}^8F^o_{3\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 7242.24 | 60 | — | V E | 13804.08 | 4.07 | $1^o_{2\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 7237.92 | 1 | — | V E | 13812.32 | 2.37 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 7197.08 | 80 | — | V E | 13890.70 | 0.75 | $c\ {}^8D^o_{1\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 7189.57 | 800 | — | V E | 13905.21 | 5.39 | $1^o_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 7173.40 | 12 | — | V E | 13936.56 | 6.45 | $(c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}})$ |
| 7172.26 | 600 | — | V E | 13938.77 | 8.75 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 7169.85 | 4 | — | V E | 13943.46 | 3.54 | $a\ {}^8G^o_{4\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 7164.90 | 25 | — | V E | 13953.09 | 3.08 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 7153.12 | 15 | — | V E | 13976.07 | 6.06 | $a\ {}^8G^o_{1\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 7146.13 | 40 | — | V E | 13989.74 | 9.77 | $a\ {}^8G^o_{\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 7141.17 | 25 | — | V E | 13999.46 | 9.49 | $a\ {}^8G^o_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 7133.16 | 100 | — | V E | 14015.18 | 5.36 | $1^o_{2\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 7121.43 | 3 | — | V E | 14038.26 | 8.18 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 7118.86 | 800 | — | V E | 14043.33 | 3.32 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 7116.77 | 150 | — | V E | 14047.45 | 7.47 | $a\ {}^8G^o_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 7109.83 | 10 | — | V E | 14061.16 | 1.18 | $a\ {}^8G^o_{\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 7101.73 | 20 | — | V E | 14077.20 | 7.16 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 7094.77 | 2 | — | V E | 14091.01 | 0.94 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8P_{3\frac{1}{2}}$ |
| 7085.52 | 50 | — | V E | 14109.41 | 9.46 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 7084.18 | 20 | —? | {V E V? | 14112.08 | 2.15 | $a\ {}^8G^o_{3\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 7065.80 | 12 | — | V E | 14148.78 | 8.79 | $a\ {}^8G^o_{1\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 7063.34 | 1 | — | V E | 14153.71 | 3.75 | $a\ {}^8G^o_{3\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 7058.02 | 80 | — | V E | 14164.38 | 4.37 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 7056.69 | 6 | — | V E | 14167.05 | 7.06 | $a\ {}^8G^o_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 7054.62 | 200 | — | V E | 14171.21 | 1.25 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 7051.00 | 200 | — | V E | 14178.48 | 8.48 | $c\ {}^8D^o_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 7043.30 | 20 | — | V E | 14193.98 | 4.01 | $3^o_{4\frac{1}{2}} - y\ {}^{10}P_{4\frac{1}{2}}$ |
| 7017.73 | 60 | — | V E | 14245.70 | 5.76 | $1^o_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 7012.50 | 12 | — | V E | 14256.33 | 6.41 | $2^o_{2\frac{1}{2}} - y\ {}^{10}P_{2\frac{1}{2}}$ |
| 7011.4 | 3*d*? | — | V E | 14258.6 | 8.76 | $a\ {}^8G^o_{1\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 7006.16 | 1000 | — | V E | 14269.22 | 9.21 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 7000.75 | 200 | — | V E | 14280.25 | 0.21 | $c\ {}^8D^o_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 6996.76 | 1500 | — | V E | 14288.40 | 8.45 | $(c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}})$ |
| 6988.75 | 100 | — | V E | 14304.77 | 4.81 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6971.66 | 100 | — | V E | 14339.84 | 9.86 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6959.24 | 150 | — | V E | 14365.43 | 5.44 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6951.74 | 8 | — | V E | 14380.93 | 1.04 | $(c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8P_{3\frac{1}{2}})$ |
| 6947.28 | 15 | — | V E | 14390.16 | 0.18 | $c\ {}^8D^o_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 6945.98 | 150 | — | V E | 14392.85 | 2.87 | $c\ {}^8D^o_{3\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 6945.05 | 8 | — | V E | 14394.78 | 4.77 | $a\ {}^8G^o_{2\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6939.63 | 10 | — | V E | 14406.02 | 5.99 | $a\ {}^8F^o_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 6920.62 | 250 | — | V E | 14445.60 | 5.63 | $c\ {}^8D^o_{4\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}}$ |
| 6901.1 | tr | | | 14486.5 | 6.51 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 6900.73 | 200 | — | V E | 14487.23 | 7.23 | $c\ {}^8D^o_{4\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 6885.71 | 4 | — | V E | 14518.83 | 8.85 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 6884.40 | 10 | — | V E | 14521.59 | 1.60 | $a\ {}^8F^o_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 6878.51 | 15 | — | V E | 14534.03 | 4.05 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6858.43 | 5 | — | V E | 14576.58 | 6.52 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^{10}P_{4\frac{1}{2}}$ |
| 6857.13 | 600 | — | V E | 14579.30 | 9.31 | $c\ {}^8D^o_{4\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 6846.60 | 1200 | — | V E | 14601.77 | 1.78 | $a\ {}^{10}P^o_{4\frac{1}{2}} - z\ {}^{10}P_{3\frac{1}{2}}$ |
| 6834.82 | 10 | — | V E | 14626.94 | 6.93 | $a\ {}^8G^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6821.90 | 8 | — | V E | 14654.64 | 4.66 | $a\ {}^8G^o_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 6813.17 | 6 | — | V E | 14673.41 | 3.34 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6765.52 | 8 | — | V E | 14776.76 | 6.74 | $3^o_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6764.61 | 3 | — | V E | 14778.75 | 8.74 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 6752.67 | 2000 | — | V E | 14804.88 | 4.90 | $a\ {}^8G^o_{7\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6727.83 | 125 | — | V E | 14859.54 | 9.53 | $a\ {}^{10}P^o_{3\frac{1}{2}} - 2_{4\frac{1}{2}}$ |
| 6724.18 | 3 | — | V E | 14867.60 | 7.53 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6718.14 | 150 | — | V E | 14880.97 | 0.98 | $a\ {}^8G^o_{5\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6713.08 | 4 | — | V E | 14892.19 | 2.21 | $a\ {}^8G^o_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6704.18 | 60 | — | V E | 14911.96 | 1.94 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^8P_{3\frac{1}{2}}$ |
| 6702.12 | 40 | — | V E | 14916.54 | 6.58 | $a\ {}^8G^o_{5\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 6685.00 | 2 | — | V E | 14954.74 | 4.66 | $a\ {}^8G^o_{5\frac{1}{2}} - y\ {}^{10}P_{4\frac{1}{2}}$ |
| 6681.23 | 1000 | — | V E | 14963.18 | 3.21 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^{10}P_{4\frac{1}{2}}$ |
| 6660.69 | 2 | — | V E | 15009.32 | 9.29 | $a\ {}^{10}P^o_{3\frac{1}{2}} - 1_{4\frac{1}{2}}$ |
| 6634.36 | 1500 | — | V E | 15068.89 | 8.89 | $a\ {}^{10}P^o_{3\frac{1}{2}} - z\ {}^{10}P_{2\frac{1}{2}}$ |
| 6622.28 | 50 | — | V E | 15096.38 | 6.31 | $a\ {}^8F^o_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 6610.04 | 80 | — | V E | 15124.33 | 4.28 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^{10}P_{4\frac{1}{2}}$ |
| 6607.98 | 3 | — | V E | 15129.05 | 9.02 | $c\ {}^8D^o_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 6568.00 | 100 | — | V E | 15221.14 | 1.10 | $c\ {}^8D^o_{3\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 6494.11 | 80 | — | V E | 15394.32 | 4.30 | $c\ {}^8D^o_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6480.11 | 200 | — | V E | 15427.58 | 7.57 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 6449.08 | 4 | — | V E | 15501.81 | 1.79 | $a\ {}^8G^o_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6442.53 | 15 | — | V E | 15517.57 | 7.51 | $a\ {}^8D^o_{4\frac{1}{2}} - 1_{4\frac{1}{2}}$ |
| 6434.28 | 5 | — | V E | 15537.47 | 7.39 | $a\ {}^8G^o_{5\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6380.95 | 600 | — | V E | 15667.33 | 7.27 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 6346.65 | 400 | — | V E | 15752.00 | 1.99 | $a\ {}^{10}P^o_{3\frac{1}{2}} - 2_{4\frac{1}{2}}$ |
| 6314.22 | 50 | — | V E | 15832.90 | 2.87 | $c\ {}^8D^o_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 6305.15 | 1500 | — | V E | 15855.68 | 5.67 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^{10}P_{4\frac{1}{2}}$ |
| 6299.07 | 40 | — | V E | 15870.98 | 0.95 | $c\ {}^8D^o_{3\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 6260.31 | 40 | — | V E | 15969.24 | 9.17 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 6180.42 | 300 | 15 | {IV V E | 16175.66 | 5.59 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^{10}D_{5\frac{1}{2}}$ |
| 6106.19 | 100 | — | V E | 16372.30 | 2.29 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^{10}F_{5\frac{1}{2}}$ |
| 6080.65 | 300 | — | V E | 16441.07 | 1.07 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 6071.34 | 5 | — | V E | 16466.28 | 6.16 | $b\ {}^8D^o_{3\frac{1}{2}} - 1_{4\frac{1}{2}}$ |
| 6049.50 | 80 | — | V E | 16525.73 | 5.76 | $b\ {}^8D^o_{4\frac{1}{2}} - z\ {}^{10}P_{3\frac{1}{2}}$ |
| 6036.05 | 5 | — | V E | 16562.55 | 2.46 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 6011.12 | 30 | — | V E | 16631.24 | 1.23 | $b\ {}^8D^o_{3\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 6004.57 | 500 | — | V E Eu to v | 16649.38 | 9.36 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 5987.11 | 150 | — | V E | 16697.93 | 7.96 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^8P_{3\frac{1}{2}}$ |
| 5986.22 | 10 | — | V E | 16700.42 | 0.37 | $4^o_{4\frac{1}{2}} - y\ {}^8D_{4\frac{1}{2}}$ |
| 5977.69 | 15 | — | V E | 16724.25 | 4.26 | $b\ {}^8D^o_{4\frac{1}{2}} - 1_{4\frac{1}{2}}$ |
| 5964.87 | 5? | — | V E | 16760.19 | 0.21 | $b\ {}^8D^o_{1\frac{1}{2}} - z\ {}^{10}F_{2\frac{1}{2}}$ |
| 5956.48 | 200 | — | V E | 16783.80 | 3.86 | $b\ {}^8D^o_{4\frac{1}{2}} - z\ {}^{10}P_{3\frac{1}{2}}$ |
| 5951.60 | 80 | — | V E | 16797.56 | 7.64 | $a\ {}^{10}P^o_{4\frac{1}{2}} - z\ {}^{10}F_{3\frac{1}{2}}$ |
| 5904.07 | 800 | — | V E | 16932.79 | 2.79 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$ |
| 5897.62 | 200 | — | V E | 16951.30 | 1.26 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 5884.59 | 30 | — | V E | 16988.84 | 8.83 | $a\ {}^8F^o_{5\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$ |
| 5877.26 | 1000 | — | V E | 17010.03 | 0.06 | $a\ {}^{10}P^o_{5\frac{1}{2}} - z\ {}^{10}P_{3\frac{1}{2}}$ |
| 5871.81 | 30 | — | V E | 17025.82 | 5.89 | $a\ {}^8D^o_{3\frac{1}{2}} - 3_{3\frac{1}{2}}$ |
| 5860.73 | 1000 | — | V E | 17058.00 | 8.02 | $b\ {}^8D^o_{3\frac{1}{2}} - 1_{4\frac{1}{2}}$ |
| 5856.96 | 150 | — | V E | 17068.98 | 9.02 | $b\ {}^8D^o_{3\frac{1}{2}} - z\ {}^{10}F_{3\frac{1}{2}}$ |
| 5855.24 | 300 | — | V E | 17074.00 | 4.03 | $a\ {}^8F^o_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$ |

TABLE VII.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 5845.71 | 80 | — | V E | 17101.83 | 1.84 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 5840.47 | 200 | — | V E | 17117.18 | 7.16 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8D_{3\frac{1}{2}}$ |
| 5820.99 | 200 | — | V E | 17174.46 | 4.46 | *a* $^8F^o_{1\frac{1}{2}} - z\ ^8D_{1\frac{1}{2}}$ |
| 5815.85 | 250 | — | V E | 17189.63 | 9.64 | *a* $^8F^o_{2\frac{1}{2}} - z\ ^8D_{2\frac{1}{2}}$ |
| 5807.05 | 100 | — | V E | 17215.68 | 5.73 | *a* $^8F^o_{\frac{1}{2}} - z\ ^8D_{1\frac{1}{2}}$ |
| 5801.30 | 40 | — | V E | 17232.75 | 2.77 | *a* $^8F^o_{2\frac{1}{2}} - z\ ^8D_{2\frac{1}{2}}$ |
| 5790.02 | ? | — | V E | 17266.32 | 6.34 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 5774.56 | 15 | 2 | IV, V E | 17312.55 | 2.54 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 5770.05 | 20 | — | V E | 17326.08 | 6.10 | *a* $^6D^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 5749.41 | 500 | — | V E | 17388.28 | 8.28 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 5733.86 | 4000 | — | V E | 17435.44 | 5.41 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 5728.32 | 60 | — | V E | 17452.30 | 2.31 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 5721.99 | 200 | — | V E | 17471.60 | 1.62 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8P_{4\frac{1}{2}}$ |
| 5644.84 | 300 | — | V E | 17710.39 | 0.41 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 5630.31 | 15 | — | V E | 17756.10 | 6.12 | $2^o_{3\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 5624.76 | 10 | — | V E | 17773.62 | 3.52 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^8P_{4\frac{1}{2}}$? |
| 5621.43 | 100 | — | V E | 17784.14 | 4.16 | *a* $^8G^o_{6\frac{1}{2}} - y\ ^8D_{5\frac{1}{2}}$ |
| 5616.21 | 300 | — | V E | 17800.67 | 0.72 | *b* $^8D^o_{3\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 5601.94 | 4 | — | V E | 17846.01 | 6.02 | *b* $^8D^o_{1\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 5597.21 | 200 | — | V E | 17861.10 | 1.11 | *a* $^{10}P^o_{5\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 5588.07 | 15 | — | V E | 17890.21 | 0.29 | $2^o_{3\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 5586.16 | 100 | — | V, V E | 17896.43 | 6.50 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$ |
| 5583.68 | 800 | — | V E | 17904.38 | 4.46 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 5560.69 | 600 | — | V E | 17978.40 | 8.40 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 5555.28 | 6 | — | V E | 17995.91 | 5.96 | *a* $^8D^o_{2\frac{1}{2}} - \ 4_{2\frac{1}{2}}$ |
| 5552.23 | 20 | — | V E | 18005.79 | 5.85 | *a* $^8G^o_{5\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 5545.01 | 250 | — | V E | 18029.24 | 9.25 | *a* $^{10}P^o_{3\frac{1}{2}} - \ 4_{2\frac{1}{2}}$ |
| 5526.73 | 8 | — | V E | 18088.87 | 8.78 | *b* $^8D^o_{2\frac{1}{2}} - \ 3_{2\frac{1}{2}}$ |
| 5510.58 | 80 | — | V E | 18141.88 | 1.88 | *a* $^8G^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 5500.43 | 600 | — | V E | 18175.36 | 5.35 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5470.53 | 50 | — | V E | 18274.70 | 4.75 | *b* $^8D^o_{3\frac{1}{2}} - \ 3_{2\frac{1}{2}}$ |
| 5469.72 | 800 | 25 | IV, V E | 18277.40 | 7.43 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 5441.17 | 40 | — | V E | 18373.31 | 3.34 | $4^o_{4\frac{1}{2}} - z\ ^6F_{3\frac{1}{2}}$ |
| 5430.13 | 3 | — | V E | 18410.66 | 0.74 | *a* $^6D^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 5420.35 | 6 | — | V E | 18443.88 | 3.93 | $3^o_{4\frac{1}{2}} - \ 7_{4\frac{1}{2}}$? |
| 5419.876 | 150 | — | V E | 18445.49 | 5.51 | *a* $^{10}P^o_{2\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 5404.95 | 15, 5 | — | V E | 18496.43 | 6.58 | *a* $^8G^o_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 5394.321 | 125 | — | V E | 18532.88 | 2.85 | *b* $^8D^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 5393.659 | 100 | — | V E | 18535.15 | 5.14 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 5385.04 | 15 | — | V E | 18564.81 | 4.83 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 5375.393 | 100 | — | V E | 18598.13 | 8.12 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 5374.70 | 10 | — | V E | 18600.53 | 0.60 | $1^o_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 5372.216 | 300 | — | V E | 18609.13 | 9.13 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5371.621 | 40 | — | V E | 18611.19 | 1.19 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 5370.39 | 4 | — | V E | 18615.46 | 5.44 | *a* $^8G^o_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 5366.814 | 10 | — | V E | 18627.86 | 7.81 | $3^o_{4\frac{1}{2}} - y\ ^6F_{4\frac{1}{2}}$ |
| 5362.599 | 10 | — | V E | 18642.50 | 2.46 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5362.165 | 15 | — | V E | 18644.01 | 3.97 | *c* $^8D^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 5358.72 | 1 | — | V E | 18656.00 | 5.89 | $3^o_{4\frac{1}{2}} - \ 8_{4\frac{1}{2}}$? |
| 5357.790 | 50 | — | V E | 18659.23 | 9.18 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 5347.63 | 1 | — | V E | 18694.69 | 4.70 | *a* $^8G^o_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 5324.10 | 15 | — | V E | 18777.31 | 7.30 | *c* $^8D^o_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 5315.94 | 4 | — | V E | 18806.13 | 6.13 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5309.17 | 6 | — | V E | 18830.11 | 0.06 | *c* $^8D^o_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 5308.62 | 4 | — | V E | 18832.06 | 2.01 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^6P_{3\frac{1}{2}}$ |
| 5306.022 | 20 | — | V E | 18841.28 | 1.25 | *c* $^8D^o_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 5304.923 | 25 | — | V E | 18845.18 | 5.15 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 5303.43 | 30 | — | V E | 18850.49 | 0.47 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 5296.88 | 8 | — | V E | 18873.80 | 3.69 | *c* $^8D^o_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 5296.65 | 6 | — | V E | 18874.62 | 4.61 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^8D_{3\frac{1}{2}}$ |
| 5289.52 | 6 | — | V E | 18900.06 | 0.02 | *a* $^8G^o_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 5284.45 | 15 | — | V E | 18918.19 | 8.17 | $3^o_{4\frac{1}{2}} - z\ ^6F_{3\frac{1}{2}}$ |
| 5282.16 | 20 | — | V E | 18926.40 | 6.40 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8P_{4\frac{1}{2}}$ |
| 5272.66 | 8 | — | V E | 18960.50 | 0.49 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 5267.322 | 40 | — | V E | 18979.71 | 9.72 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{5\frac{1}{2}}$ |
| 5257.15 | 1 | — | V E | 19016.43 | 6.38 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 5256.030 | 50 | — | V E | 19020.49 | 0.43 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 5252.14 | 500 | 500 | V E, III | 19034.58 | 4.48 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 5220.297 | 300 | — | V E | 19150.68 | 0.68 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5220.16 | 15 | 1 | IV, V E | 19151.18 | 1.16 | $3^o_{4\frac{1}{2}} - z\ ^6F_{4\frac{1}{2}}$ |
| 5213.04 | 5 | — | V E | 19177.34 | 7.31 | *b* $^8D^o_{1\frac{1}{2}} - \ 4_{2\frac{1}{2}}$ |
| 5210.488 | 200 | — | V E | 19186.73 | 6.70 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8P_{3\frac{1}{2}}$ |
| 5205.64 | 6 | — | V E | 19204.60 | 4.58 | *a* $^8G^o_{5\frac{1}{2}} - \ 7_{4\frac{1}{2}}$ |
| 5200.549 | 30 | — | V E | 19223.40 | 3.35 | $4^o_{4\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 5199.211 | 60 | — | V E | 19228.35 | 8.30 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8P_{4\frac{1}{2}}$ |
| 5191.081 | 250 | 5 | IV E | 19258.46 | 8.41 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 5187.237 | 250 | — | V E | 19272.73 | 2.70 | *a* $^8F^o_{2\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 5186.915 | 200 | — | V E | 19273.93 | 3.91 | *a* $^8F^o_{1\frac{1}{2}} - z\ ^8F_{\frac{1}{2}}$ |
| 5179.919 | 125 | — | V E | 19299.96 | 9.96 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^8D_{5\frac{1}{2}}$ |
| 5178.843 | 100 | 15 | IV, V E | 19303.97 | 3.88 | $4^o_{4\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 5178.104 | 100 | — | V E | 19306.72 | 6.70 | *a* $^8F^o_{5\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 5176.285 | 800 | 5 | IV E | 19313.51 | 3.46 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{5\frac{1}{2}}$ |
| 5175.839 | 50 | — | V E | 19315.17 | 5.18 | *a* $^8F^o_{\frac{1}{2}} - z\ ^8F_{\frac{1}{2}}$ |
| 5167.82 | 3*d*? | — | V E | 19345.15 | 5.32 | *a* $^8F^o_{1\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 5164.542 | 150 | — | V E | 19357.42 | 7.40 | *a* $^{10}P^o_{5\frac{1}{2}} - z\ ^8P_{4\frac{1}{2}}$ |
| 5162.47 | 50*d* | — | V E | 19365.20 | 5.14 | $2^o_{2\frac{1}{2}} - z\ ^6F_{2\frac{1}{2}}$ |
| 5161.614 | 20 | — | V E | 19368.40 | 8.38 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 5160.896 | 100 | — | V E | 19371.10 | 1.07 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8P_{3\frac{1}{2}}$ |
| 5160.105 | 40 | — | V E | 19374.07 | 4.02 | *a* $^8F^o_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 5156.76 | 200 | — | V E | 19386.63 | 6.59 | *a* $^8F^o_{\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 5156.29 | 5, 10 | — | V E | 19388.40 | 8.46 | *a* $^8G^o_{4\frac{1}{2}} - z\ ^6F_{4\frac{1}{2}}$ |
| 5149.841 | 50 | — | V E | 19412.68 | 2.67 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8P_{4\frac{1}{2}}$ |
| 5149.375 | 20 | — | V E | 19414.44 | 4.41 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 5140.839 | 400 | — | V E | 19446.67 | 6.64 | *a* $^8F^o_{1\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 5130.98 | 3 | — | V E | 19484.04 | 3.99 | *a* $^8F^o_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 5130.28 | 200 | — | V E | 19486.70 | 6.68 | *a* $^8F^o_{2\frac{1}{2}} - y\ ^8P_{3\frac{1}{2}}$ |
| 5125.56 | 400 | — | V E | 19504.64 | 4.61 | *a* $^{10}P^o_{5\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 5111.930 | 30 | — | V E | 19556.65 | 6.61 | *a* $^8F^o_{1\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 5108.91 | 500 | — | V E | 19568.21 | 8.19 | *a* $^8F^o_{5\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 5107.406 | 60 | — | V E | 19573.97 | 4.01 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^8D_{2\frac{1}{2}}$ |
| 5103.136 | 12 | — | V E | 19590.36 | 0.29 | $4^o_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 5100.937 | 100 | — | V E | 19598.80 | 8.78 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 5098.38 | 400 | — | V E | 19608.62 | 8.60 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 5096.063 | 200 | — | V E | 19617.53 | 7.49 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 5092.251 | 600 | — | V E | 19632.22 | 2.20 | *a* $^8F^o_{5\frac{1}{2}} - z\ ^8F_{5\frac{1}{2}}$ |
| 5081.56 | 10 | — | V E | 19673.53 | 3.59 | $2^o_{2\frac{1}{2}} - z\ ^6F_{2\frac{1}{2}}$ |
| 5071.023 | 200 | — | V E | 19714.41 | 4.39 | *a* $^8F^o_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 5062.862 | 150 | — | V E | 19746.18 | 6.18 | *b* $^8D^o_{1\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 5057.228 | 20 | — | V E | 19768.18 | 8.18 | $3^o_{4\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 5050.878 | 300 | — | V E | 19793.04 | 2.97 | *a* $^8F^o_{2\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 5041.34 | 2 | — | V E | 19830.48 | 0.41 | $4^o_{4\frac{1}{2}} - z\ ^8D_{3\frac{1}{2}}$ |
| 5036.70 | 3 | — | V E | 19848.75 | 8.71 | $3^o_{4\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 5031.562 | 80 | — | V E | 19869.02 | 9.02 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5031.290 | 250 | — | V E | 19870.09 | 0.09 | *a* $^8F^o_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 5030.48 | 1 | — | V E | 19873.29 | 3.36 | $2^o_{2\frac{1}{2}} - z\ ^6F_{1\frac{1}{2}}$ |
| 5029.74 | 3 | — | V E | 19876.21 | 6.21 | *a* $^8G^o_{5\frac{1}{2}} - z\ ^8F_{5\frac{1}{2}}$ |
| 5023.133 | 200 | — | V E | 19902.36 | 2.38 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 5020.75 | 1 | — | V E | 19911.81 | 1.81 | *a* $^8G^o_{5\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$? |
| 5020.368 | 80 | 60 | V E?, IV | 19913.31 | 3.36 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 5019.361 | 100 | — | V E | 19917.31 | 7.35 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8D_{3\frac{1}{2}}$ |
| 5014.71 | 2 | — | V E | 19935.79 | 5.82 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 5010.821 | 400 | — | V E | 19951.26 | 1.25 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 4998.373 | 200 | — | V E | 20000.94 | 0.94 | *a* $^8G^o_{4\frac{1}{2}} - z\ ^6F_{3\frac{1}{2}}$ |
| 4991.41 | 5 | — | V | 20028.85 | 8.79 | *c* $^8D^o_{4\frac{1}{2}} - \ 7_{4\frac{1}{2}}$? |
| 4984.905 | 60 | — | V E | 20054.98 | 4.99 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 4981.31 | 20 | — | V E | 20069.46 | 9.42 | $2^o_{2\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 4973.896 | 30 | — | V E | 20099.37 | 9.33 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 4968.575 | 50 | — | V E | 20120.90 | 0.87 | *c* $^8D^o_{3\frac{1}{2}} - \ 7_{4\frac{1}{2}}$ |
| 4965.047 | 60 | — | V E | 20135.19 | 5.12, 5.37 | $3^o_{4\frac{1}{2}} - z\ ^6D_{4\frac{1}{2}}$ (*a* $^8F^o_{4\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$) |
| 4958.788 | 800 | 125 | V E, IV | 20160.61 | 0.48 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4956.59 | 5 | — | V E | 20169.55 | 9.55 | *a* $^8G^o_{4\frac{1}{2}} - z\ ^6F_{4\frac{1}{2}}$ |

TABLE VII.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4954.025 | 50 | — | V E | 20179.99 | 9.96 | $a\ {}^5F^\circ_5 - z\ {}^5F_5$ |
| 4946.01 | 4 | — | V E | 20212.69 | 2.67 | $c\ {}^5D^\circ_4 - y\ {}^5F_4$ |
| 4945.411 | 8 | — | V E | 20215.14 | 5.15 | $2^\circ_2 - x\ {}^5P_2$ |
| 4944.70 | 20 | — | V E | 20218.05 | 8.04 | $a\ {}^5F^\circ_5 - y\ {}^{10}P_4$ |
| 4936.93 | 20 | — | V E | 20249.87 | 9.86 | $a\ {}^{10}P^\circ_3 - z\ {}^5P_3$ |
| 4936.155 | 50 | — | V E | 20253.05 | 3.01 | $a\ {}^5F^\circ_5 - y\ {}^{10}P_5$ |
| 4923.578 | 60 | — | V E | 20304.78 | 4.75 | $c\ {}^5D^\circ_3 - z\ {}^5F_4$ |
| 4916.78 | 25 | — | V E | 20332.85 | 2.83 | $c\ {}^5D^\circ_3 - 8_3$ |
| 4910.838 | 50 | — | V E | 20357.45 | 7.43 | $b\ {}^5D^\circ_4 - z\ {}^{10}D_3$ |
| 4894.30 | 600 | 10 | IV E | 20426.24 | 6.26 | $b\ {}^5D^\circ_1 - z\ {}^5D_1$ |
| 4892.11 | 30 | — | V E | 20435.39 | 5.35 | $a\ {}^5F^\circ_2 - y\ {}^{10}P_3$ |
| 4888.542 | 40 | — | V E | 20450.30 | 0.27 | $c\ {}^5D^\circ_2 - z\ {}^5F_3$ |
| 4886.44 | 8 | — | V E | 20459.10 | 9.06 | $c\ {}^5D^\circ_1 - z\ {}^5F_1$ |
| 4881.925 | 200 | — | V E | 20478.02 | 8.00<br>8.10 | $a\ {}^5G^\circ_3 - z\ {}^5F_3$<br>$(a\ {}^5F^\circ_1 - z\ {}^5P_1)$ |
| 4878.049 | 30 | — | V E | 20494.29 | 4.24 | $b\ {}^5D^\circ_3 - z\ {}^{10}D_4$ |
| 4875.966 | 50 | — | V E | 20503.04 | 3.03 | $c\ {}^5D^\circ_4 - z\ {}^5F_5$ |
| 4873.339 | 150 | — | V E | 20514.10 | 4.06 | $b\ {}^5D^\circ_1 - z\ {}^5D_2$ |
| 4871.94 | 10 | — | V E | 20519.99 | 9.94 | $a\ {}^5F^\circ_4 - y\ {}^{10}P_4$ |
| 4868.87 | 4 | — | V E | 20532.93 | 2.91 | $a\ {}^5G^\circ_2 - z\ {}^5F_2$ |
| 4865.02 | 400 | — | V E | 20549.18 | 9.10 | $b\ {}^5D^\circ_2 - z\ {}^5D_1$ |
| 4861.32 | 15 | — | V E | 20564.82 | 4.81 | $c\ {}^5D^\circ_1 - z\ {}^5F_1$ |
| 4850.82 | 5 | — | V E | 20609.33 | 9.36 | $a\ {}^5G^\circ_4 - x\ {}^5P_3$ |
| 4846.58 | 1 | — | V E | 20627.36 | 7.30 | $a\ {}^5G^\circ_4 - z\ {}^5F_3$ |
| 4844.32 | 10 | — | V E | 20636.98 | 6.90 | $b\ {}^5D^\circ_2 - z\ {}^5D_2$ |
| 4840.03 | 2 | — | V E | 20655.28 | 5.12 | $c\ {}^5D^\circ_3 - x\ {}^5P_2$ |
| 4839.616 | 40 | — | V E | 20657.04 | 6.99 | $z\ {}^5D^\circ_2 - z\ {}^5F_2$ |
| 4834.232 | 300 | — | V E | 20680.06 | 0.03 | $b\ {}^5D^\circ_2 - z\ {}^5D_3$ |
| 4828.55 | 3 | — | V E | 20704.38 | 4.31 | $a\ {}^5F^\circ_3 - y\ {}^{10}P_3$ |
| 4821.955 | 60 | — | V E | 20732.70 | 2.68 | $a\ {}^5G^\circ_3 - z\ {}^5F_1$ |
| 4821.17 | 1 | — | V E | 20736.08 | 6.02 | $c\ {}^5D^\circ_4 - z\ {}^5F_4$ |
| 4815.911 | 3 | — | V E | 20758.72 | 8.72 | $c\ {}^5D^\circ_3 - z\ {}^5F_3$ |
| 4813.76 | 8 | — | V E | 20768.00 | 8.03 | $a\ {}^5D^\circ_4 - 1_4$ |
| 4806.165 | 40 | — | V E | 20800.82 | 0.77 | $a\ {}^5F^\circ_4 - y\ {}^{10}P_3$ |
| 4805.817 | 100 | — | V E | 20802.32 | 2.30 | $b\ {}^5D^\circ_3 - z\ {}^{10}F_4$ |
| 4803.536 | 80 | — | V E | 20812.20 | 2.18 | $a\ {}^{10}P^\circ_4 - y\ {}^5P_4$ |
| 4802.575 | 80 | — | V E | 20816.36 | 6.35 | $a\ {}^{10}F^\circ_4 - z\ {}^{10}P_3$ |
| 4801.05 | 500 | — | V E | 20822.97 | 2.87 | $b\ {}^5D^\circ_2 - z\ {}^5D_3$ |
| 4800.100 | 60 | — | V E | 20827.10 | 7.07 | $a\ {}^5G^\circ_1 - z\ {}^5F_1$ |
| 4799.859 | 60 | ? | V E | 20828.14 | 8.10 | $c\ {}^5D^\circ_3 - z\ {}^5F_3$ |
| 4797.508 | 6 | — | V E | 20838.35 | 8.31 | $4^\circ_4 - y\ {}^5F_5$ |
| 4796.94 | 3 | — | V E | 20840.82 | 0.78 | $a\ {}^5G^\circ_1 - z\ {}^5F_1$ |
| 4793.265 | 20 | — | V E | 20856.80 | 6.76 | $c\ {}^5D^\circ_2 - z\ {}^5F_2$ |
| 4791.150 | 40 | — | V E | 20866.00 | 6.00 | $b\ {}^5D^\circ_3 - z\ {}^5D_4$ |
| 4786.908 | 150 | — | V E | 20884.49 | 4.47 | $b\ {}^5D^\circ_3 - z\ {}^5D_4$ |
| 4776.15 | 3 | — | V E | 20931.53 | 1.48 | $a\ {}^5G^\circ_4 - x\ {}^5P_4$ |
| 4775.855 | 20 | — | V E | 20932.82 | 2.82 | $a\ {}^5G^\circ_4 - z\ {}^5F_4$ |
| 4772.728 | 30 | — | V E | 20946.54 | 6.53 | $a\ {}^5G^\circ_3 - z\ {}^5F_3$ |
| 4765.534 | 15 | — | V E | 20978.16 | 8.08 | $4^\circ_4 - y\ {}^5F_4$ |
| 4757.791 | 80 | — | V E | 21012.30 | 2.28 | $a\ {}^{10}F^\circ_5 - 2_4$ |
| 4756.15 | 1 | — | V E | 21019.55 | 9.56 | $a\ {}^5G^\circ_3 - x\ {}^5P_3$ |
| 4755.347 | 30 | — | V E | 21023.10 | 3.13 | $a\ {}^5G^\circ_4 - x\ {}^5P_3$ |
| 4737.41 | 3 | — | V E | 21102.70 | 2.67 | $a\ {}^5F^\circ_4 - y\ {}^{10}P_3$ |
| 4734.427 | 100 | — | V E | 21115.99 | 5.96 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}P_4$ |
| 4732.60 | 600 | — | V E | 21124.14 | 4.10 | $b\ {}^5D^\circ_4 - z\ {}^5D_4$ |
| 4728.468 | 300 | — | V E | 21142.60 | 2.57 | $b\ {}^5D^\circ_3 - z\ {}^5D_4$ |
| 4726.725 | 40 | — | V E | 21150.40 | 0.32 | $4^\circ_4 - y\ {}^5F_3$ |
| 4725.784 | 20 | — | V E | 21154.61 | 4.55 | $c\ {}^5D^\circ_3 - x\ {}^5P_3$ |
| 4721.273 | 50 | — | V E | 21174.82 | 4.81 | $a\ {}^5D^\circ_4 - z\ {}^5F_4$ |
| 4719.040 | 60 | — | V E | 21184.84 | 4.81 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}P_5$ |
| 4717.35 | 6*d* | — | V E<br>V | 21192.43 | 2.48 | $a\ {}^{10}P^\circ_5 - z\ {}^5F_4$ |
| 4716.576 | 30 | — | V E | 21195.91 | 5.93 | $a\ {}^{10}P^\circ_4 - y\ {}^5P_3$ |
| 4715.974 | 4 | — | V E | 21198.61 | 8.55 | $c\ {}^5D^\circ_2 - x\ {}^5P_2$ |
| 4711.975 | 80 | — | V E | 21216.60 | 6.56 | $b\ {}^5D^\circ_4 - z\ {}^{10}D_5$ |
| 4711.685 | 6 | — | V E | 21217.91 | 7.89 | $a\ {}^5G^\circ_4 - z\ {}^5D_4$ |
| 4707.33 | 3 | — | V E | 21237.54 | 7.53 | $a\ {}^{10}P^\circ_4 - y\ {}^5P_4$ |
| 4699.03 | 2 | — | V E | 21275.05 | 5.06 | $a\ {}^5D^\circ_2 - z\ {}^5P_3$ |
| 4681.853 | 6 | — | V E | 21353.10 | 3.04 | $c\ {}^5D^\circ_4 - x\ {}^5P_3$ |
| 4675.78 | 8 | — | V E | 21380.84 | 0.81 | $c\ {}^5D^\circ_3 - x\ {}^5P_4$ |
| 4675.27 | 5 | — | V E | 21383.17 | 3.14 | $3^\circ_4 - y\ {}^5F_5$ |

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4674.54 | 8 | — | V E | 21386.51 | 6.50 | $a\ {}^5G^\circ_5 - z\ {}^5D_4$ |
| 4666.448 | 40 | 5 | IV<br>V E | 21423.60 | 3.64 | $a\ {}^{10}P^\circ_4 - z\ {}^5F_3$ |
| 4664.272 | 30 | — | V E | 21433.59 | 3.57 | $c\ {}^5D^\circ_4 - x\ {}^5P_4$ |
| 4659.421 | 20 | — | V E | 21455.91 | 5.89 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}P_5$ |
| 4658.97 | 3 | — | V E | 21457.98 | 8.01 | $a\ {}^5G^\circ_4 - z\ {}^5D_3$ |
| 4654.986 | 100 | — | V E | 21476.35 | 6.33 | $b\ {}^5D^\circ_5 - z\ {}^5D_4$ |
| 4653.75 | 10 | — | V E | 21482.05 | 2.04 | $b\ {}^5D^\circ_4 - z\ {}^5D_3$ |
| 4649.98 | 6 | — | V E | 21499.47 | 9.45 | $a\ {}^{10}F^\circ_4 - 2_4$ |
| 4646.326 | 40 | — | V E | 21516.38 | 6.36 | $a\ {}^5D^\circ_3 - z\ {}^5P_3$ |
| 4639.001 | 200 | — | V E | 21550.35 | 0.32<br>0.38 | $b\ {}^5D^\circ_4 - z\ {}^{10}D_5$<br>$a\ {}^{10}P^\circ_5 - y\ {}^5P_5$ |
| 4627.66 | 40 | — | V E | 21603.16 | 3.13 | $a\ {}^{10}F^\circ_4 - z\ {}^{10}P_4$ |
| 4622.63 | 8 | — | V E | 21626.67 | 6.62 | $a\ {}^5G^\circ_3 - z\ {}^5D_3$ |
| 4620.45 | 15*d*? | — | V E | 21636.87 | 6.95 | $a\ {}^5D^\circ_4 - 1_4$ |
| 4615.44 | 3 | — | V E | 21660.36 | 0.35 | $a\ {}^{10}P^\circ_3 - z\ {}^5F_3$ |
| 4613.97 | 1 | — | V E | 21667.26 | 7.22 | $c\ {}^5D^\circ_3 - z\ {}^5D_4$ |
| 4610.94 | 1 | — | V E | 21681.50 | 1.53 | $a\ {}^5G^\circ_3 - z\ {}^5D_3$ |
| 4608.030 | 40 | — | V E | 21695.19 | 5.15 | $3^\circ_4 - y\ {}^5F_3$ |
| 4605.578 | 4 | — | V E | 21706.74 | 6.73 | $b\ {}^5D^\circ_3 - z\ {}^5P_4$ |
| 4602.30 | 1 | — | V E | 21722.20 | 2.26 | $c\ {}^5D^\circ_1 - z\ {}^5D_1$ |
| 4601.05 | 500 | 4 | IV E | 21728.10 | 8.07 | $a\ {}^{10}F^\circ_3 - z\ {}^{10}F_3$ |
| 4597.91 | 500 | 15 | IV E<br>IV | 21742.94 | 2.90 | $a\ {}^{10}F^\circ_4 - z\ {}^{10}F_3$ |
| 4596.978 | 400 | 2 | IV E | 21747.35 | 7.33 | $a\ {}^{10}F^\circ_3 - z\ {}^{10}F_3$ |
| 4583.330 | 20 | — | V E | 21812.10 | 2.06 | $c\ {}^5D^\circ_4 - z\ {}^5D_4$ |
| 4582.53 | 400 | — | V E | 21815.91 | 5.80 | $b\ {}^5D^\circ_4 - z\ {}^5D_3$ |
| 4582.38 | 300 | — | V E | 21816.63 | 6.57 | $a\ {}^5D^\circ_4 - z\ {}^5P_3$ |
| 4581.086 | 200 | — | V E | 21822.79 | 2.75 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}F_4$ |
| 4571.54 | 2 | — | V E | 21868.36 | 8.36 | $a\ {}^5D^\circ_3 - z\ {}^5F_3$ |
| 4570.977 | 40 | — | V E | 21871.05 | 1.05 | $a\ {}^5D^\circ_3 - y\ {}^5P_3$ |
| 4570.04 | 1 | — | V E | 21875.54 | 5.46 | $a\ {}^5G^\circ_3 - z\ {}^5D_3$ |
| 4566.86 | 2 | — | V E | 21890.77 | 0.75 | $a\ {}^{10}P^\circ_3 - z\ {}^5F_3$ |
| 4563.397 | 10 | — | V E | 21907.38 | 7.34 | $c\ {}^5D^\circ_3 - z\ {}^5D_3$ |
| 4558.080 | 250 | 2 | IV E | 21932.93 | 2.92 | $a\ {}^{10}F^\circ_4 - z\ {}^{10}F_4$ |
| 4554.989 | 50 | — | V E | 21947.82 | 7.80 | $a\ {}^5D^\circ_4 - z\ {}^5P_3$ |
| 4552.44 | 2 | — | V E | 21960.11 | 0.10 | $c\ {}^5D^\circ_4 - z\ {}^5D_3$ |
| 4551.455 | 30 | — | V E | 21964.86 | 4.83 | $b\ {}^5D^\circ_4 - z\ {}^5P_4$ |
| 4550.954 | 150 | — | V E | 21967.28 | 7.26 | $a\ {}^{10}F^\circ_6 - z\ {}^{10}F_5$ |
| 4550.41 | 3 | — | V E | 21969.90 | 9.85 | $a\ {}^5G^\circ_4 - z\ {}^5D_3$ |
| 4550.05 | 3 | — | V E | 21971.64 | 1.59 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}P_4$ |
| 4544.36 | 2 | — | V F | 21999.15 | 9.15 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}F_5$ |
| 4540.016 | 200 | — | V E | 22020.20 | 0.18 | $a\ {}^5G^\circ_5 - y\ {}^5F_4$ |
| 4530.646 | 4 | — | V E | 22065.73 | 5.74 | $a\ {}^{10}P^\circ_5 - z\ {}^5F_5$ |
| 4525.61 | 5 | — | V E | 22090.29 | 0.27 | $a\ {}^5G^\circ_4 - z\ {}^5D_4$ |
| 4524.388 | 15 | — | V E | 22096.26 | 6.26 | $a\ {}^5G^\circ_5 - y\ {}^5F_4$ |
| 4523.875 | 20 | — | V E | 22098.77 | 8.76 | $a\ {}^5D^\circ_3 - z\ {}^5F_3$ |
| 4522.82 | 250 | 50? | III<br>V E | 22103.92 | 3.82 | $a\ {}^{10}P^\circ_5 - y\ {}^{10}P_4$ |
| 4521.94 | 150 | — | V E | 22108.22 | 8.19 | $a\ {}^5G^\circ_6 - y\ {}^5F_5$ |
| 4521.296 | 100 | — | V E | 22111.37 | 1.36 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}F_5$ |
| 4520.070 | 150 | — | V E | 22117.37 | 7.35 | $a\ {}^5D^\circ_3 - z\ {}^5P_3$ |
| 4517.10 | 30 | — | V E | 22131.91 | 1.86 | $a\ {}^5G^\circ_5 - y\ {}^5F_5$ |
| 4515.01 | 3 | — | V E | 22142.16 | 2.12 | $2^\circ_3 - y\ {}^5F_3$ |
| 4514.67 | 5 | — | V E | 22143.82 | 3.79 | $a\ {}^5G^\circ_5 - y\ {}^5F_5$ |
| 4514.505 | 200 | — | V E | 22144.63 | 4.60 | $a\ {}^{10}P^\circ_5 - y\ {}^{10}P_5$ |
| 4510.380 | 30*d*? | — | V E | 22164.88 | 4.86 | $a\ {}^5S^\circ_2 - 1_4$ |
| 4509.082 | 50 | — | V E | 22171.27 | 1.26 | $a\ {}^5D^\circ_4 - y\ {}^5P_3$ |
| 4508.4 | 1 | — | V E | 22174.6 | 4.76 | $a\ {}^5G^\circ_1 - z\ {}^5D_1$ |
| 4506.931 | 60 | — | V E | 22181.85 | 1.86 | $a\ {}^5D^\circ_3 - 1_4$ |
| 4506.333 | 200 | 2 | IV E | 22184.79 | 4.74 | $a\ {}^{10}F^\circ_5 - z\ {}^{10}F_5$ |
| 4500.640 | 20 | — | V E | 22212.85 | 2.86 | $a\ {}^5D^\circ_4 - y\ {}^5P_4$ |
| 4498.276 | 300 | 2 | IV E | 22224.53 | 4.46 | $a\ {}^5S^\circ_2 - z\ {}^{10}P_3$ |
| 4494.853 | 25 | — | V E | 22241.46 | 1.46 | $a\ {}^5D^\circ_3 - z\ {}^{10}P_3$ |
| 4488.401 | 80 | — | V E | 22273.42 | 3.38 | $a\ {}^5D^\circ_4 - z\ {}^5P_3$ |
| 4486.352 | 100 | — | V E | 22283.59 | 3.56 | $a\ {}^5G^\circ_6 - y\ {}^5F_4$ |
| 4484.469 | 20 | — | V E | 22292.95 | 2.95 | $a\ {}^5D^\circ_3 - z\ {}^5F_4$ |
| 4483.328 | 300 | 1 | IV E | 22298.62 | 8.59 | $b\ {}^5D^\circ_4 - z\ {}^5P_4$ |
| 4482.00 | 2 | — | V E | 22305.23 | 5.17 | $2^\circ_3 - y\ {}^5F_3$ |
| 4481.056 | 300 | 4 | IV E | 22309.93 | 9.92 | $a\ {}^{10}F^\circ_4 - z\ {}^{10}F_4$ |
| 4478.795 | 250 | 2 | IV E | 22321.19 | 1.20 | $a\ {}^5D^\circ_5 - z\ {}^{10}F_4$ |

TABLE VII.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4471.29 | 200 | 1 | IV E | 22358.66 | 8.65 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4467.227 | 80 | — | V E | 22378.99 | 9.06 | *a* $^8D^o_{1\frac{1}{2}} - z\ ^8P_{1\frac{1}{2}}$ |
| 4466.547 | 500* | ? | V E | 22382.40 | 2.44 | *a* $^{10}F^o_{3\frac{1}{2}} - z\ ^{10}F_{2\frac{1}{2}}$ |
| 4463.247 | 80 | — | V E | 22398.95 | 8.97 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 4453.931 | 60 | — | V E | 22445.80 | 5.80 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4449.953 | 15 | — | V E | 22465.86 | 5.91 | *a* $^6G^o_{4\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4446.487 | 250 | 1 | IV E | 22483.37 | 3.33 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 4438.26 | 150*? | 8 | IV E | 22525.05 | 5.04 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4438.13 | 30 | — | V E | 22525.71 | 5.71 | *b* $^8D^o_{1\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 4437.453 | 8 | — | V E | 22529.15 | 9.17 | *a* $^{10}P^o_{4\frac{1}{2}} - y\ ^{10}P_{4\frac{1}{2}}$ |
| 4436.225 | 200 | 1 | IV E | 22535.38 | 5.38 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4433.635 | 60 | — | V E | 22548.55 | 8.55 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4430.344 | 5 | — | V E | 22565.30 | 5.34 | *a* $^{10}F^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 4427.606 | 60 | — | V E | 22579.25 | 9.25 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4426.151 | 80 | — | V E | 22586.63 | 6.69 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^{10}P_{2\frac{1}{2}}$ |
| 4424.102 | 40 | — | V E | 22597.13 | 7.12 | *b* $^8D^o_{1\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 4422.55 | 20 | — | V E | 22605.06 | 5.03 | *a* $^{10}F^o_{6\frac{1}{2}} - z\ ^{10}P_{5\frac{1}{2}}$ |
| 4421.24 | 200 | — | V E | 22611.76 | 1.71 | *a* $^{10}P^o_{3\frac{1}{2}} - y\ ^{10}P_{2\frac{1}{2}}$ |
| 4419.032 | 800 | 3 | IV E | 22623.06 | 3.10 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 4408.248 | 400 | ? | IV E | 22678.39 | 8.38 | *a* $^{10}F^o_{6\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4406.67 | 400 | ? | IV E | 22686.52 | 6.55 | *a* $^{10}P^o_{3\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 4400.18 | 25 | — | V E | 22719.98 | 9.96 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 4394.719 | 25 | — | V E | 22748.21 | 8.18 | *a* $^{10}F^o_{7\frac{1}{2}} - z\ ^{10}F_{6\frac{1}{2}}$ |
| 4391.445 | 15 | — | V E | 22765.17 | 5.22 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4390.953 | 300 | 4 | IV E | 22767.72 | 7.72 | *a* $^8S^o_{3\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 4389.69 | 6 | — | V E | 22774.27 | 4.29 | *a* $^8G^o_{5\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 4388.98 | 15 | — | V E | 22777.97 | 7.92 | *a* $^8G^o_{4\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4387.674 | 300 | 4 | IV E | 22784.74 | 4.72 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 4383.119 | 150 | — | V E | 22808.42 | 8.41 | *b* $^8D^o_{1\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 4382.061 | 60 | — | V E | 22813.92 | 3.88 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4380.642 | 100 | — | V E | 22821.31 | 1.28 | *b* $^8D^o_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 4374.243 | 30 | — | V E | 22854.70 | 4.65 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 4369.771 | 500 | 5 | IV E | 22878.09 | 8.13 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^{10}F_{1\frac{1}{2}}$ |
| 4367.31 | 15 | 2 | IV, V E | 22890.98 | 0.87 | *c* $^8D^o_{1\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 4364.140 | 25 | — | V E | 22907.60 | 7.56 | *a* $^8S^o_{3\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 4360.917 | 250 | 1 | IV E | 22924.53 | 4.56 | *a* $^8D^o_{3\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 4359.636 | 30 | — | V E | 22931.27 | 1.25 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 4359.152 | 40 | — | V E | 22933.82 | 3.80<br>3.94 | *a* $^{10}F^o_{3\frac{1}{2}} - \ 3_{3\frac{1}{2}}$<br>(*b* $^8D^o_{3\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$) |
| 4356.74 | 10 | — | V E | 22946.51 | 6.53 | *a* $^8G^o_{5\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 4352.669 | 15 | 8 | IV, V E | 22967.97 | 8.00 | *c* $^8D^o_{4\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4347.310 | 400 | — | V E | 22996.29 | 6.28 | *a* $^{10}P^o_{3\frac{1}{2}} - y\ ^{10}P_{2\frac{1}{2}}$ |
| 4345.24 | 1 | — | V E | 23007.24 | 7.25 | *b* $^8D^o_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 4344.487 | 40 | — | V E | 23011.23 | 1.24 | *a* $^8S^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4344.300 | 100 | — | V E | 23012.22 | 2.21 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 4342.179 | 1500 | 5 | IV E | 23023.46 | 3.49<br>3.32 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{2\frac{1}{2}}$<br>(*b* $^8D^o_{4\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$) |
| 4341.282 | 600 | 3 | IV E | 23028.22 | 8.24 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 4337.510 | 80 | 100 | V E, III | 23048.24 | 8.15 | *c* $^8D^o_{2\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 4336.24 | 4 | — | V E | 23054.99 | 5.01 | *c* $^8D^o_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 4335.290 | 25 | — | V E | 23060.05 | 0.08 | *c* $^8D^o_{2\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4330.948 | 20 | — | V E | 23083.16 | 3.14 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4330.606 | 600 | 3 | IV E | 23084.99 | 4.96 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4327.125 | 1500 | 2000 | V E, I | 23103.56 | 3.47 | *a* $^8D^o_{1\frac{1}{2}} - z\ ^{10}F_{1\frac{1}{2}}$ |
| 4326.61 | 3 | — | V E | 23106.31 | 6.31 | *c* $^8D^o_{1\frac{1}{2}} - y\ ^8F_{1\frac{1}{2}}$ |
| 4326.324 | 20 | — | V E | 23107.83 | 7.77 | *c* $^8D^o_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 4326.00 | 4 | — | V E | 23109.57 | 9.58 | *a* $^8G^o_{3\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4325.566 | 200 | — | V E | 23111.88 | 1.90 | *a* $^{10}P^o_{4\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 4324.566 | 20 | — | V E | 23117.23 | 7.22 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 4324.064 | 150 | 2 | IV E | 23119.91 | 9.91 | *b* $^8D^o_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 4323.03 | 2 | — | V E | 23125.44 | 5.52 | *c* $^8D^o_{2\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 4322.195 | 125 | 3 | IV E | 23129.91 | 9.95 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^{10}F_{2\frac{1}{2}}$ |
| 4321.110 | 200 | — | V E | 23135.72 | 5.74 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4316.266 | 150 | — | V E | 23161.68 | 1.65<br>1.51 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$<br>(*b* $^8D^o_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$) |
| 4316.052 | 600 | 4 | IV E | 23162.83 | 2.81 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 4310.981 | 200 | — | V E | 23190.08 | 0.12 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4308.233 | 40 | — | V E | 23204.87 | 4.88 | *a* $^{10}F^o_{3\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 4304.087 | 25 | — | V E | 23227.22 | 7.25 | *c* $^8D^o_{3\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4298.23 | 1 | — | V E | 23258.87 | 8.88 | *a* $^6G^o_{3\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 4296.30 | 400 | — | V E | 23269.32 | 9.23 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 4296.076 | 1000 | 3 | IV E | 23270.53 | 0.55 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$ |
| 4292.747 | 25 | — | V E | 23288.58 | 8.57 | *c* $^8D^o_{2\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 4291.39 | 4 | — | V E | 23295.94 | 5.94 | *a* $^8G^o_{2\frac{1}{2}} - y\ ^8F_{1\frac{1}{2}}$ |
| 4280.490 | 1500 | 8 | IV E | 23355.26 | 5.29 | *a* $^8D^o_{1\frac{1}{2}} - z\ ^{10}F_{2\frac{1}{2}}$ |
| 4275.033 | 4 | — | V E | 23385.07 | 5.04 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4274.1 | 2? | — | V E | 23390.2 | 0.30<br>0.33 | *c* $^8D^o_{3\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$<br>*a* $^8G^o_{4\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 4268.731 | 150 | — | V E | 23419.60 | 9.61 | *b* $^8D^o_{4\frac{1}{2}} - y\ ^8P_{4\frac{1}{2}}$ |
| 4264.013 | 5 | — | V E | 23445.51 | 5.54 | *a* $^8D^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 4262.092 | 2500 | 150 | V E, III | 23456.08 | 6.08 | *a* $^{10}F^o_{6\frac{1}{2}} - z\ ^{10}F_{5\frac{1}{2}}$ |
| 4253.366 | 800 | 3 | IV E | 23504.20 | 4.20 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$ |
| 4251.733 | 2000 | 15 | IV E | 23513.23 | 3.24 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 4246.568 | 150 | — | V E | 23541.82 | 1.81 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 4241.276 | 80 | — | V E | 23571.20 | 1.13 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 4235.07 | 15 | — | V E | 23605.74 | 5.72 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 4229.803 | 200 | — | V E | 23635.13 | 5.08 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 4227.140 | 200 | — | V E | 23650.02 | 9.98 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 4225.148 | 100 | — | V E | 23661.17 | 1.26 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 4223.020 | 60 | — | V E | 23673.09 | 3.13 | $2^o_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 4217.195 | 500 | 3 | IV E | 23705.79 | 5.80 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4215.023 | 600 | ? | IV? E | 23718.01 | 8.03 | *a* $^8S^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4212.001 | 800 | 5 | IV E | 23735.02 | 5.03 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4208.752 | 8 | — | V E | 23753.35 | 3.37 | *b* $^8D^o_{4\frac{1}{2}} - y\ ^8P_{3\frac{1}{2}}$ |
| 4208.365 | 8 | — | V E | 23755.53 | 5.50 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 4204.857 | 300 | 3 | IV E | 23775.35 | 5.28 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4197.069 | 150 | — | V E | 23819.46 | 9.45 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4191.355 | 10 | — | V E | 23852.94 | 2.74 | *b* $^8D^o_{2\frac{1}{2}} - z\ ^8P_{1\frac{1}{2}}$ |
| 4191.067 | 800 | 4 | IV E | 23853.57 | 3.53 | *a* $^8S^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4188.099 | 60 | — | V E | 23870.48 | 0.53 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4184.252 | 2000 | 8 | IV E | 23892.42 | 2.41 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4176.794 | 15 | — | V E | 23935.08 | 5.06 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4173.556 | 100 | — | V E | 23953.66 | 3.62 | *a* $^8F^o_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 4170.108 | 150 | 10 | IV, V E | 23973.46 | 3.45 | *a* $^8S^o_{3\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 4167.159 | 40 | — | V E | 23990.42 | 0.45 | *a* $^8D^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 4163.092 | 250 | 100 | III, V E | 24013.86 | 3.86 | *a* $^{10}F^o_{6\frac{1}{2}} - z\ ^{10}F_{6\frac{1}{2}}$ |
| 4162.732 | 500 | — | V E | 24015.94 | 5.94 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$ |
| 4154.862 | 250 | — | V E | 24061.43 | 1.40 | *b* $^8D^o_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 4153.510 | 125 | — | V E | 24069.26 | 9.23 | *a* $^8F^o_{3\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 4141.017 | 25 | — | V E | 24141.87 | 1.85 | *a* $^8F^o_{1\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 4140.450 | 100 | — | V E | 24145.18 | 5.17 | *a* $^{10}F^o_{3\frac{1}{2}} - \ 4_{3\frac{1}{2}}$ |
| 4132.275 | 2000 | 6 | IV E | 24192.95 | 2.97 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4130.372 | 3000 | 10 | IV E | 24204.09 | 4.10<br>4.25 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$<br>(*a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$) |
| 4128.391 | 10 | — | V E | 24215.70 | 5.76 | *a* $^8D^o_{2\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4127.721 | 25 | — | V E | 24219.64 | 9.64 | *a* $^8F^o_{2\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 4115.376 | 80 | — | V E | 24292.29 | 2.26 | *a* $^8F^o_{1\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 4108.401 | 50 | — | V E | 24333.53 | 3.53 | *a* $^8F^o_{1\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 4098.900 | 400 | 2 | IV E | 24389.93 | 9.92 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 4098.606 | 3000 | 6 | IV E | 24391.68 | 1.68 | *a* $^{10}F^o_{7\frac{1}{2}} - z\ ^{10}D_{6\frac{1}{2}}$ |
| 4098.030 | 20 | — | V E | 24395.11 | 5.16 | *b* $^8D^o_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 4094.478 | 300 | 5 | IV E | 24416.27 | 6.25 | *a* $^{10}F^o_{2\frac{1}{2}} - \ 4_{2\frac{1}{2}}$ |
| 4088.807 | 10 | — | V E | 24450.13 | 0.16 | *a* $^{10}D^o_{4\frac{1}{2}} - \ 1_{4\frac{1}{2}}$ |
| 4085.564 | 2000 | 3 | IV E | 24469.54 | 9.58 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 4078.444 | 1200 | 4 | IV E | 24512.26 | 2.31 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 4075.470 | 15 | — | V E | 24530.14 | 0.18 | *a* $^8D^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 4073.759 | 1500 | 5 | IV E | 24540.45 | 0.48 | *a* $^{10}F^o_{7\frac{1}{2}} - z\ ^{10}F_{7\frac{1}{2}}$ |
| 4073.195 | 400 | 1 | IV E | 24543.85 | 3.85 | *a* $^8S^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4070.390 | 200 | 1 | IV E | 24560.76 | 0.85 | *a* $^8D^o_{3\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 4070.288 | 600 | 1 | IV E | 24561.38 | 1.43 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4066.563 | 5 | — | V E | 24583.87 | 3.82 | *a* $^8F^o_{4\frac{1}{2}} - \ 9_{3\frac{1}{2}}$ |
| 4064.7 | 1 | — | V E† | 24595.1 | 5.22 | *c* $^8D^o_{1\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 4063.59 | 200 | 1 | IV E | 24601.86 | 1.84 | *a* $^{10}F^o_{1\frac{1}{2}} - \ 4_{2\frac{1}{2}}$ |

* Blend with arc line.

TABLE VII.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4059.370 | 80 | — | V E | 24627.43 | 7.43 | *a* $^5F^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 4049.429 | 1200 | 1 | IV E | 24687.89 | 7.89 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 4045.148 | 100 | — | V E | 24714.02 | 4.04 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{5\frac{1}{2}}$ |
| 4037.897 | 1200 | 2 | IV E | 24758.40 | 8.38 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 4037.332 | 1500 | 3 | IV E | 24761.86 | 1.88 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 4013.953 | 60 | — | V E | 24906.08 | 6.08 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5P_{2\frac{1}{2}}$ |
| 4003.850 | 30 | — | V E | 24968.90 | 8.92 | *a* $^{10}P^o_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 4002.75 | 3 | — | V E | 24975.79 | 5.83 | *a* $^{10}D^o_{4\frac{1}{2}} - \ 1_{4\frac{1}{2}}$ |
| 4001.257 | 600 | 2 | IV E | 24985.11 | 5.12 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3997.764 | 300 | — | V E | 25006.94 | 6.93 | *b* $^5D^o_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3994.165 | 800 | 1 | IV E | 25029.47 | 9.46 | *a* $^{10}F^o_{2\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3993.213 | 200 | — | IV E | 25035.44 | 5.43 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 3991.692 | 15 | — | V E | 25044.98 | 5.01 | *b* $^5D^o_{4\frac{1}{2}} - y\ ^{10}P_{4\frac{1}{2}}$ |
| 3987.214 | 600 | 3 | IV E | 25073.10 | 3.17 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3983.008 | 80 | — | V E | 25099.58 | 9.58 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3977.94 | 1 | — | V E | 25131.56 | 1.58 | *a* $^5F^o_{4\frac{1}{2}} - \ 9_{5\frac{1}{2}}$ |
| 3976.87 | 3 | — | V E | 25138.32 | 8.11 | *a* $^5F^o_{3\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3974.223 | 10 | — | V E | 25155.06 | 5.01 | *a* $^{10}P^o_{3\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3973.981 | 500 | 1 | IV E | 25156.59 | 6.59 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3971.754 | 300 | — | V E | 25170.70 | 0.71 | *a* $^{10}F^o_{1\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3971.062 | 100 | — | V E | 25175.08 | 5.06 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3969.293 | 300 | — | V E | 25186.30 | 6.34 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3968.261 | 60 | — | V E | 25192.86 | 2.86 | *a* $^{10}D^o_{3\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 3966.850 | 15 | — | V E | 25201.81 | 1.82 | *a* $^5D^o_{2\frac{1}{2}} - \ 4_{3\frac{1}{2}}$ |
| 3959.523 | 500? | — | V E | 25248.45 | 8.38 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}F_{7\frac{1}{2}}$ |
| 3959.436 | 300? | — | V E | 25249.00 | 9.05 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3957.672 | 1000 | 2 | IV E | 25260.26 | 0.33 | *a* $^5D^o_{1\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3956.137 | 8 | — | V E | 25270.05 | 0.12 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3952.395 | 2 | — | V E | 25293.98 | 3.98 | *b* $^5D^o_{4\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 3952.00 | 300 | — | V E | 25296.51 | 6.54 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 3944.088 | 6 | — | V E | 25347.25 | 7.29 | *a* $^{10}D^o_{3\frac{1}{2}} - \ 1_{4\frac{1}{2}}$ |
| 3934.824 | 300? | — | V E | 25406.93 | 6.89 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 3923.246 | 300 | 1 | IV E | 25481.91 | 1.92 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3918.90 | 2 | — | V E | 25510.17 | 0.15 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3918.236 | 150 | — | V E | 25514.49 | 4.53 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3916.508 | 3000 | 2 | IV E | 25525.75 | 5.81 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3913.785 | 20 | — | V E | 25543.50 | 3.52 | *a* $^{10}F^o_{3\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3913.70 | 1 | — | V E | 25544.06 | 4.08 | *a* $^5F^o_{2\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 3908.143 | 8 | — | V E | 25580.38 | 0.36 | *a* $^{10}P^o_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3904.984 | 5 | — | V E | 25601.07 | 1.08 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3902.398 | 1000 | 4 | IV E | 25618.04 | 8.08 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3898.402 | 10 | — | V E | 25644.30 | 4.31 | *a* $^{10}P^o_{4\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3896.416 | 10 | — | V E | 25657.37 | 7.36 | *a* $^{10}F^o_{5\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3895.230 | 200 | — | V E | 25665.18 | 5.20 | *a* $^{10}F^o_{2\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3894.696 | 2000 | 15 | IV E | 25668.70 | 8.70 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 3887.157 | 40 | — | V E | 25718.48 | 8.53 | *a* $^{10}D^o_{4\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 3881.94 | 30 | — | V E | 25753.04 | 3.00 | *a* $^{10}F^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3881.84 | 50 | — | V E | 25753.71 | 3.69 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3875.46 | 100 | — | V E | 25796.10 | 6.13 | *a* $^{10}F^o_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3872.62 | 60 | — | V E | 25815.02 | 5.03 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3871.54 | 80 | — | V E | 25822.22 | 2.21 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 3867.26 | 60 | — | V E | 25850.80 | 0.79 | *a* $^{10}F^o_{1\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3863.98 | 8 | — | V E | 25872.74 | 2.74 | *a* $^5F^o_{3\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3855.56 | 200 | — | V E | 25929.24 | 9.26 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}F_{5\frac{1}{2}}$ |
| 3854.177 | 50 | — | V E | 25938.55 | 8.59 | *a* $^{10}F^o_{1\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3852.45 | 1000 | 10? | IV E | 25950.18 | 0.15 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 3850.97 | 1200 | 30 | III E | 25960.15 | 0.14 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}F_{1\frac{1}{2}}$ |
| 3850.69 | 800 | 20? | IV E | 25962.04 | 1.98 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 3845.47 | 20 | — | V E | 25997.28 | 7.32 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3844.579 | 500 | 2 | IV E | 26003.30 | 3.33 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 3843.80 | 25 | — | V E | 26008.57 | 8.60 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3839.64 | 300 | 1 | IV E | 26036.75 | 6.79 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3838.75 | 2 | — | V E | 26042.79 | 2.75 | *a* $^5D^o_{1\frac{1}{2}} - y\ ^5D_{2\frac{1}{2}}$ |
| 3836.91 | 300 | 3 | IV E | 26055.28 | 5.26 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3832.16 | 4 | — | V E | 26087.57 | 7.54 | *a* $^5D^o_{3\frac{1}{2}} - y\ ^5D_{1\frac{1}{2}}$ |
| 3831.80 | 100 | — | V E | 26090.02 | 9.99 | *a* $^{10}D^o_{3\frac{1}{2}} - \ 2_{4\frac{1}{2}}$ |
| 3831.20 | 3 | — | V E | 26094.11 | 4.11 | *a* $^5F^o_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3828.69 | 6*d*? | — | V E | 26111.21 | 1.42 | *a* $^{10}P^o_{3\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3828.000 | 30 | — | V E | 26115.92 | 5.92 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3826.05 | 200 | — | V E | 26129.23 | 9.25 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^{10}D_{4\frac{1}{2}}$ |
| 3822.17 | 80 | — | V E | 26155.75 | 5.81 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3821.51 | 20 | 4 | V E, IV | 26160.27 | 0.26 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^{10}D_{3\frac{1}{2}}$ |
| 3816.64 | 250 | 8 | IV E | 26193.65 | 3.67 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^{10}P_{4\frac{1}{2}}$ |
| 3813.97 | 2000 | 60 | IV E | 26211.99 | 1.96 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 3809.06 | 3 | — | V E? | 26245.77 | 5.59 | *a* $^{10}P^o_{2\frac{1}{2}} - y\ ^5D_{2\frac{1}{2}}$ |
| 3807.65 | 25 | — | V E | 26255.49 | 5.48 | *a* $^5D^o_{3\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3798.39 | 20 | — | V E | 26319.50 | 9.43 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3796.37 | 2500 | 200 | IV E | 26333.50 | 3.44 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}F_{2\frac{1}{2}}$ |
| 3795.25 | 20 | — | V E | 26341.27 | 1.26 | *a* $^5D^o_{1\frac{1}{2}} - z\ ^{10}D_{2\frac{1}{2}}$ |
| 3791.72 | 30 | — | V E | 26365.80 | 5.78 | *a* $^{10}F^o_{3\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3791.17 | 300 | — | V E | 26369.62 | 9.60 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3787.56 | 400 | 6 | IV E | 26394.75 | 4.73 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^5D_{5\frac{1}{2}}$ |
| 3779.13 | 3 | — | V E | 26453.63 | 3.60 | *a* $^5D^o_{3\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3769.45 | 100 | 1 | IV E | 26521.56 | 1.57 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3768.39 | 2000 | 125 | IV E | 26529.02 | 9.00 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 3767.04 | 500 | 4 | IV E | 26538.53 | 8.57 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3764.60 | 50 | — | V E | 26555.73 | 5.69 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3763.33 | 60 | — | V E | 26564.69 | 4.70 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3763.00 | 50 | — | V E | 26567.02 | 7.03 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 3760.92 | 100 | — | V E | 26581.71 | 1.70 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3760.71 | 200 | 1 | IV E | 26583.20 | 3.17 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3759.00 | 300 | 6 | IV E | 26595.29 | 5.25 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}F_{3\frac{1}{2}}$ |
| 3758.31 | 200 | 4 | IV E | 26600.17 | 0.17 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3755.56 | 40 | — | V E | 26619.65 | 9.64 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3748.88 | 50 | — | V E | 26667.08 | 7.04 | *a* $^{10}P^o_{4\frac{1}{2}} - \ 6_{5\frac{1}{2}}$ |
| 3743.47 | 2000 | 80 | IV E | 26705.62 | 5.62 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 3732.45 | 100 | — | V E | 26784.46 | 4.42 | *a* $^{10}D^o_{4\frac{1}{2}} - \ 3_{3\frac{1}{2}}$ |
| 3730.84 | 1000 | 15 | IV E | 26796.02 | 6.00 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3723.69 | 20 | — | V E | 26847.47 | 7.48 | *a* $^5F^o_{4\frac{1}{2}} - y\ ^5F_{5\frac{1}{2}}$ |
| 3722.068 | 100 | — | V E | 26859.16 | 9.41 | *a* $^5F^o_{3\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 3719.53 | 300 | 2 | IV E | 26877.50 | 7.52 | *a* $^5D^o_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3718.67 | 4 | — | V E | 26883.72 | 3.80 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3716.36 | 1000 | 25 | IV E | 26900.42 | 0.46 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^{10}F_{4\frac{1}{2}}$ |
| 3712.70 | 2000 | 25 | IV E | 26926.94 | 6.93 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3709.13 | 50 | — | V E | 26952.86 | 2.81 | *a* $^{10}F^o_{7\frac{1}{2}} - z\ ^5F_{6\frac{1}{2}}$ |
| 3707.71 | 8 | — | V E | 26963.18 | 2.97 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$? |
| 3707.46 | 1 | — | V E | 26965.00 | 4.93 | *a* $^{10}F^o_{5\frac{1}{2}} - y\ ^5P_{4\frac{1}{2}}$ |
| 3702.48 | 2 | — | V E | 27001.27 | 1.15 | *a* $^5F^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3699.73 | 800 | — | V E | 27021.34 | 1.34 | *a* $^5D^o_{1\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3697.73 | 1000 | 40 | IV E | 27035.95 | 5.96 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^5P_{2\frac{1}{2}}$ |
| 3695.96 | 3 | — | V E | 27048.90 | 8.94 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 3694.309 | 15 | — | V E | 27060.99 | 0.97 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 3687.74 | 800 | 15 | IV E | 27109.19 | 9.14 | *a* $^5D^o_{1\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3676.09 | 1 | — | V E | 27195.10 | 5.08 | *a* $^5F^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3671.20 | 1500 | 80 | IV E | 27231.32 | 1.29 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^{10}F_{5\frac{1}{2}}$ |
| 3669.18 | 2 | — | V E | 27246.31 | 6.20 | *a* $^{10}P^o_{3\frac{1}{2}} - \ 7_{4\frac{1}{2}}$ |
| 3666.30 | 2 | — | V E | 27267.72 | 7.70 | *a* $^5F^o_{1\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3662.26 | 800 | 40 | IV E | 27297.80 | 7.77 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^5P_{2\frac{1}{2}}$ |
| 3656.152 | 1500 | 60 | IV E | 27343.40 | 3.39 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^{10}P_{3\frac{1}{2}}$ |
| 3654.62 | 2000*d* | 100 | III E | 27354.86 | 4.82 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3650.95 | 100 | — | V E | 27382.36 | 2.32 | *b* $^5D^o_{3\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3649.44 | 80 | — | V E | 27393.69 | 3.65 | *b* $^5D^o_{1\frac{1}{2}} - y\ ^5D_{2\frac{1}{2}}$ |
| 3649.23 | 8 | — | V E | 27395.26 | 5.24 | *a* $^5F^o_{4\frac{1}{2}} - y\ ^5F_{5\frac{1}{2}}$ |
| 3647.87 | 10 | — | V E | 27405.48 | 5.43 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3647.64 | 2 | — | V E | 27407.21 | 7.17 | *a* $^5F^o_{3\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3647.20 | 5 | 5 | IV, V E | 27410.51 | 0.50 | *a* $^{10}F^o_{4\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3646.19 | 3000 | 150 | III E | 27418.10 | 8.08 | *a* $^{10}D^o_{5\frac{1}{2}} - z\ ^{10}F_{6\frac{1}{2}}$ |
| 3645.62 | 300 | 6 | IV E | 27422.39 | 2.43 | *a* $^5D^o_{3\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3645.35 | 6 | — | V E | 27424.42 | 4.27 | (*a* $^{10}F^o_{3\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$) |
| 3644.59 | 4 | — | V E | 27430.14 | 0.08 | *a* $^{10}P^o_{3\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3641.39 | 125 | — | V E | 27454.24 | 4.21 | *a* $^5D^o_{3\frac{1}{2}} - \ 7_{4\frac{1}{2}}$ |
| 3640.18 | 50 | 2 | IV, V E | 27463.37 | 3.38 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5P_{4\frac{1}{2}}$ |
| 3637.14 | 5 | — | V E | 27486.32 | 6.32 | *a* $^{10}P^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 3634.757 | 100 | — | V E | 27504.34 | 4.34 | *b* $^5D^o_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3629.51 | 80 | — | V E | 27544.10 | 4.06 | *b* $^5D^o_{3\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3629.15 | 12*d*? | — | V E | 27546.84 | 6.84 | *a* $^5F^o_{5\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 3626.32 | 40 | — | V E | 27568.34 | 8.29 | *b* $^5D^o_{2\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3625.26 | 60 | — | V E | 27576.39 | 6.35 | *b* $^5D^o_{4\frac{1}{2}} - y\ ^5D_{5\frac{1}{2}}$ |
| 3621.28 | 6 | — | V E | 27606.70 | 6.72 | *a* $^{10}F^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |

TABLE VII.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3617.164 | 200 | 4 | IV E | 27638.12 | 8.09 | $a\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| | | | | | 8.21 | $(a\ {}^{10}F^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}})$ |
| 3614.21 | 100 | 400 | II A V E | 27660.70 | 0.71 | $a\ {}^{10}F^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3613.490 | 80 | — | V E | 27666.22 | 6.17 | $a\ {}^8D^\circ_{3\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| | | | | | 6.30 | $(a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^8P_{3\frac{1}{2}})$ |
| 3613.392 | 150 | — | V E | 27666.96 | 6.90 | $b\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8D_{4\frac{1}{2}}$ |
| 3610.76 | 200 | — | V E | 27687.14 | 7.15 | $a\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3608.753 | 200 | — | V E | 27702.53 | 2.46 | $b\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8D_{3\frac{1}{2}}$ |
| 3607.90 | 20 | — | V E | 27709.08 | 9.07 | $a\ {}^8F^\circ_{4\frac{1}{2}} - y\ {}^8F_{4\frac{1}{2}}$ |
| 3605.665 | 100 | 5 | IV E | 27726.26 | 6.28 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^8P_{3\frac{1}{2}}$ |
| 3602.00 | 20 | — | V E | 27754.46 | 4.42 | $a\ {}^8D^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3600.963 | 200 | — | V E | 27762.46 | 2.44 | $b\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^8D_{4\frac{1}{2}}$ |
| 3599.16 | 4 | — | V E | 27776.37 | 6.27 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3598.825 | 8 | — | V E | 27778.95 | 8.96 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3593.445 | 60 | — | V E | 27820.54 | 0.56 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 3592.709 | 1500*d* | — | V E | 27826.24 | 6.39 | $b\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^8D_{3\frac{1}{2}}$ |
| | | | | | 6.05 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3591.912 | 30 | — | V E | 27832.41 | 2.40 | $a\ {}^{10}F^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3591.442 | 20 | — | V E | 27836.06 | 6.06 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3590.468 | 100 | — | V E | 27843.61 | 3.68 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3587.186 | 40 | — | V E | 27869.08 | 9.06 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}P_{3\frac{1}{2}}$ |
| 3584.962 | 3000 | 50 | IV E | 27886.37 | 6.38 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 3581.91 | 200 | ? | V E | 27910.13 | 0.11 | $b\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8D_{3\frac{1}{2}}$ |
| 3580.618 | 40 | — | V E | 27920.20 | 0.20 | $a\ {}^8D^\circ_{\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3579.549 | 25 | — | V E | 27928.54 | 8.45 | $a\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3578.596 | 30 | — | V E | 27935.97 | 6.01 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3578.410 | 6 | — | V E | 27937.43 | 7.38 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3578.293 | 5 | — | V E | 27938.34 | 8.30 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3576.772 | 25 | — | V E | 27950.22 | 0.24 | $a\ {}^{10}F^\circ_{1\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 3574.740 | 150 | 2 | IV E | 27966.11 | 6.38 | $(a\ {}^8D^\circ_{4\frac{1}{2}} - 8_{4\frac{1}{2}})$ |
| 3571.933 | 300 | 10 | IV E | 27988.08 | 8.09 | $a\ {}^{10}D^\circ_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3569.566 | 40 | — | V E | 28006.64 | 6.67 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3567.72 | 2 | — | V E | 28021.13 | 1.08 | $a\ {}^8F^\circ_{4\frac{1}{2}} - y\ {}^8F_{3\frac{1}{2}}$ |
| 3567.654 | 40 | — | V E | 28021.65 | 1.65 | $a\ {}^{10}F^\circ_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3567.116 | 30 | — | V E | 28025.88 | 5.82 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| | | | | | 5.95 | $a\ {}^8D^\circ_{\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 3566.18 | 6 | — | V E | 28033.23 | 3.21 | $a\ {}^8F^\circ_{3\frac{1}{2}} - y\ {}^8F_{4\frac{1}{2}}$ |
| 3564.387 | 5 | — | V E | 28047.43 | 7.35 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3564.046 | 60 | — | V E | 28050.02 | 0.04 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3558.468 | 250 | 2 | IV E | 28093.99 | 3.89 | $a\ {}^{10}F^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3558.189 | 400 | — | V E | 28096.20 | 6.20 | $b\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8D_{4\frac{1}{2}}$ |
| 3557.053 | 1000 | 5 | IV E | 28105.16 | 5.17 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3554.802 | 30 | — | V E | 28122.96 | 2.97 | $a\ {}^{10}F^\circ_{1\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3553.716 | 40 | — | V E | 28131.55 | 1.57 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 3549.365 | 3000 | 200 | IV E | 28166.04 | 6.10 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 3545.797 | 3000 | 150 | IV E | 28194.38 | 4.44 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}F_{4\frac{1}{2}}$ |
| 3544.985 | 60 | 10? | IV E? | 28200.84 | 0.86 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3542.768 | 500 | 2 | IV E | 28218.48 | 8.49 | $a\ {}^{10}F^\circ_{4\frac{1}{2}} - z\ {}^8F_{5\frac{1}{2}}$ |
| 3542.341 | 15 | — | V E | 28221.88 | 1.88 | $a\ {}^8D^\circ_{1\frac{1}{2}} - x\ {}^8P_{2\frac{1}{2}}$ |
| 3541.492 | 6 | — | V E | 28228.65 | 8.66 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3540.456 | 15 | — | V E | 28236.91 | 6.90 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3535.32 | 4*d*? | — | V E | 28277.93 | 7.75 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3534.87 | 3 | — | V E | 28281.53 | 1.52 | $a\ {}^{10}F^\circ_{2\frac{1}{2}} - y\ {}^{10}P_{2\frac{1}{2}}$ |
| 3533.71 | 2 | — | V E | 28290.81 | 0.70 | $a\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3529.932 | 4 | — | V E | 28321.09 | 1.06 | $a\ {}^8F^\circ_{3\frac{1}{2}} - y\ {}^8F_{3\frac{1}{2}}$ |
| 3528.545 | 300 | 8 | IV E | 28332.22 | 2.30 | $a\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 3524.196 | 1000 | 40 | IV E | 28367.19 | 7.25 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - 4_{2\frac{1}{2}}$ |
| 3519.49 | 5*d*? | — | V E | 28405.12 | 5.05 | $b\ {}^8D^\circ_{2\frac{1}{2}} - 6_{2\frac{1}{2}}$ |
| 3518.632 | 30 | — | V E | 28412.04 | 2.05 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 3517.890 | 60 | — | V E | 28418.03 | 8.04 | $a\ {}^8D^\circ_{4\frac{1}{2}} - 9_{4\frac{1}{2}}$ |
| 3512.496 | 600 | 4 | IV E | 28461.67 | 1.65 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3512.219 | 800 | 8 | IV E | 28463.92 | 3.92 | $a\ {}^8S^\circ_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3510.133 | 30 | — | V E | 28480.83 | 0.92 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3509.72 | 2 | — | V E | 28484.18 | 4.11 | $a\ {}^8F^\circ_{2\frac{1}{2}} - y\ {}^8F_{2\frac{1}{2}}$ |
| 3505.512 | 2000 | 15 | IV E | 28518.37 | 8.41 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3503.206 | 60 | — | V E | 28537.15 | 7.16 | $a\ {}^8D^\circ_{2\frac{1}{2}} - x\ {}^8P_{2\frac{1}{2}}$ |
| 3494.404 | 3000 | 100 | IV E | 28609.03 | 9.00 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 3491.954 | 2000 | 100 | IV E | 28629.10 | 9.06 | $a\ {}^{10}D^\circ_{2\frac{1}{2}} - 4_{2\frac{1}{2}}$ |
| 3491.51, | 10 | — | V E | 28632.74 | 2.73 | $a\ {}^8D^\circ_{2\frac{1}{2}} - x\ {}^8P_{2\frac{1}{2}}$ |
| 3489.281 | 40 | — | V E | 28651.03 | 0.98 | $a\ {}^{10}P^\circ_{3\frac{1}{2}} - x\ {}^8P_{4\frac{1}{2}}$ |
| 3482.948 | 10 | — | V E | 28703.12 | 3.07 | $b\ {}^8D^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3482.602 | 800 | 5 | IV E | 28705.98 | 5.95 | $a\ {}^8S^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3481.797 | 3000 | 60 | IV E | 28712.61 | 2.60 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3481.275 | 5000 | 100 | IV E | 28716.92 | 6.94 | $a\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3480.547 | 60 | — | V E | 28722.92 | 2.95 | $a\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3479.975 | 6 | — | V E | 28727.65 | 7.63 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^{10}P_{2\frac{1}{2}}$ |
| 3478.027 | 20 | — | V E | 28743.73 | 3.74 | $a\ {}^{10}F^\circ_{4\frac{1}{2}} - y\ {}^{10}P_{4\frac{1}{2}}$ |
| 3473.219 | 2000 | 100 | IV E | 28783.52 | 3.51 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 3469.307 | 100 | — | V E | 28815.98 | 5.92 | $a\ {}^8S^\circ_{3\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3468.989 | 3000 | 80 | IV E | 28818.62 | 8.61 | $a\ {}^8S^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3468.083 | 200 | — | V E | 28826.15 | 6.15 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3467.267 | 3500 | 80 | IV E | 28832.93 | 2.92 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3466.952 | 600 | 2 | IV E | 28835.55 | 5.61 | $a\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3466.498 | 150 | — | V E | 28839.33 | 9.30 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 3464.132 | 100? | — | V E | 28859.02 | 8.99 | $a\ {}^8D^\circ_{4\frac{1}{2}} - x\ {}^8P_{4\frac{1}{2}}$ |
| 3463.984 | 5000 | 100 | IV E | 28860.26 | 0.21 | $a\ {}^8S^\circ_{3\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 3462.997 | 200 | 5 | IV E | 28868.48 | 8.47 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 3461.952 | 300* | — | V E | 28877.20 | 7.21 | $a\ {}^8D^\circ_{3\frac{1}{2}} - y\ {}^8P_{4\frac{1}{2}}$ |
| 3460.776 | 30 | — | V E | 28887.01 | 6.95 | $b\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3457.416 | 5 | — | V E | 28915.08 | 5.03 | $b\ {}^8D^\circ_{3\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 3454.904 | 2000 | 20 | IV E | 28936.10 | 6.12 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 3454.145 | 1500 | 12 | IV E | 28942.46 | 2.46 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}D_{4\frac{1}{2}}$ |
| 3451.914 | 25 | 15 | IV V E | 28961.17 | 1.17 | $b\ {}^8D^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3451.233 | 2000 | 10 | IV E | 28966.88 | 6.86 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3450.376 | 4000 | 25 | IV E | 28974.08 | 4.09 | $a\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3449.616 | 800 | 10 | IV E | 28980.46 | 0.46 | $a\ {}^{10}D^\circ_{3\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 3448.325 | 20 | — | V E | 28991.31 | 1.34 | $b\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3447.444 | 2 | — | V E | 28998.72 | 8.71 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^{10}P_{2\frac{1}{2}}$ |
| 3441.790 | 400 | — | V E | 29046.35 | 6.32 | $a\ {}^8S^\circ_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| 3439.990 | 6000 | 60 | IV E | 29061.55 | 1.58 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 3439.784 | 1500 | 10 | IV E | 29063.29 | 3.32 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3439.208 | 3000 | 20 | IV E | 29068.16 | 8.18 | $a\ {}^8D^\circ_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3437.966 | 8 | — | V E | 29078.66 | 8.67 | $a\ {}^8D^\circ_{4\frac{1}{2}} - x\ {}^8P_{3\frac{1}{2}}$ |
| 3434.626 | 8 | — | V E | 29106.94 | 6.93 | $4^\circ_{4\frac{1}{2}} - w\ {}^8P_{4\frac{1}{2}}$ |
| 3434.011 | 4 | — | V E | 29112.15 | 2.20 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^{10}P_{4\frac{1}{2}}$ |
| 3432.994 | 1500 | 10 | IV E | 29120.78 | 0.79 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{\frac{1}{2}}$ |
| 3430.238 | 40 | — | V E | 29144.17 | 4.22 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 3430.137 | 8 | — | V E | 29145.03 | 5.05 | $b\ {}^8D^\circ_{4\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3428.467 | 500 | — | V E | 29159.22 | 9.20 | $a\ {}^8D^\circ_{4\frac{1}{2}} - x\ {}^8P_{4\frac{1}{2}}$ |
| 3427.362 | 80 | — | V E | 29168.63 | 8.60 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 3426.832 | 8 | — | V E | 29173.14 | 3.13 | $b\ {}^8D^\circ_{4\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 3426.342 | 50 | — | V E | 29177.31 | 7.31 | $b\ {}^8D^\circ_{3\frac{1}{2}} - z\ {}^8F_{3\frac{1}{2}}$ |
| | | | | | 7.51 | $(a\ {}^{10}P^\circ_{2\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}})$ |
| 3426.246 | 10? | — | V E | 29178.13 | 8.15 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3425.930 | 600 | 3 | IV E | 29180.82 | 0.84 | $a\ {}^8D^\circ_{2\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3425.624 | 50 | — | V E | 29183.42 | 3.40 | $a\ {}^8D^\circ_{\frac{1}{2}} - z\ {}^8D_{1\frac{1}{2}}$ |
| 3424.592 | 1200 | 6 | IV E | 29192.22 | 2.20 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3423.92 | 1500* | 400* | IV E | 29197.95 | 7.93 | $a\ {}^{10}D^\circ_{2\frac{1}{2}} - z\ {}^{10}D_{2\frac{1}{2}}$ |
| 3422.751 | 500 | 4 | IV E | 29207.92 | 7.94 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^8D_{4\frac{1}{2}}$ |
| 3422.466 | 10000 | 200 | IV E | 29210.35 | 0.38 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^{10}F_{5\frac{1}{2}}$ |
| 3419.069 | 50 | — | V E | 29239.37 | 9.37 | $a\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 3418.930 | 20 | — | V E | 29240.56 | 0.51 | $a\ {}^8S^\circ_{3\frac{1}{2}} - z\ {}^8F_{4\frac{1}{2}}$ |
| 3418.733 | 2000 | 30 | IV E | 29242.25 | 2.27 | $a\ {}^{10}D^\circ_{2\frac{1}{2}} - z\ {}^{10}D_{3\frac{1}{2}}$ |
| 3417.330 | 150 | — | V E | 29254.25 | 4.18 | $a\ {}^8D^\circ_{\frac{1}{2}} - z\ {}^8D_{\frac{1}{2}}$ |
| 3416.948 | 2500 | 10 | IV E | 29257.52 | 7.51 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |
| 3414.207 | 60 | — | V E | 29281.01 | 1.02 | $a\ {}^{10}F^\circ_{3\frac{1}{2}} - y\ {}^8F_{4\frac{1}{2}}$ |
| 3413.273 | 400 | — | V E | 29289.02 | 9.02 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8D_{1\frac{1}{2}}$ |
| 3412.753 | 80 | — | V E | 29293.49 | 3.52 | $a\ {}^8D^\circ_{1\frac{1}{2}} - y\ {}^8P_{2\frac{1}{2}}$ |
| 3412.583 | 60 | — | V E | 29294.94 | 4.93 | $b\ {}^8D^\circ_{2\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3412.020 | 200 | — | V E | 29299.78 | 9.79 | $b\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8F_{2\frac{1}{2}}$ |
| 3411.268 | 10 | — | V E | 29306.24 | 6.21 | $a\ {}^8S^\circ_{3\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3409.297 | 500 | — | V E | 29323.18 | 3.21 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8P_{2\frac{1}{2}}$ |
| 3407.61 | 1500? | 3 | IV E | 29337.70 | 7.75 | $a\ {}^8D^\circ_{4\frac{1}{2}} - y\ {}^{10}P_{3\frac{1}{2}}$ |
| 3407.56 | 600? | — | V E | 29338.12 | 8.15 | $a\ {}^8D^\circ_{2\frac{1}{2}} - z\ {}^8D_{2\frac{1}{2}}$ |
| 3405.038 | 150 | — | V E | 29359.86 | 9.80 | $a\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8D_{\frac{1}{2}}$ |
| 3403.70 | 2 | — | V E | 29371.40 | 1.44 | $a\ {}^{10}P^\circ_{\frac{1}{2}} - z\ {}^8D_{\frac{1}{2}}$ |
| 3403.206 | 15 | — | V E | 29375.66 | 5.67 | $a\ {}^{10}D^\circ_{4\frac{1}{2}} - z\ {}^8D_{3\frac{1}{2}}$ |
| 3403.081 | 150 | — | V E | 29376.74 | 6.72 | $b\ {}^8D^\circ_{1\frac{1}{2}} - z\ {}^8F_{1\frac{1}{2}}$ |

* Blend with arc line.

TABLE VII.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3402.072 | 1000 | — | V E | 29385.45 | 5.52 | *a* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3401.067 | 300 | — | V E | 29394.13 | 4.14 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3399.991 | 1200 | 4 | IV E | 29403.43 | 3.49 | *a* $^5D^0_{1\frac{1}{2}} - z\ ^5F_{2\frac{1}{2}}$ |
| 3399.406 | 500 | — | V E | 29408.50 | 8.55 | *a* $^5D^0_{2\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 3396.300 | 4 | — | V E | 29435.39 | 5.41 | *b* $^5D^0_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 3395.120 | 1000 | — | V E | 29445.62 | 5.61 | *a* $^5D^0_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3393.630 | 400 | — | V E | 29458.55 | 8.57 | *a* $^5D^0_{2\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3392.530 | 2000 | 25 | IV E | 29468.10 | 8.13 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^{[3]}D_{3\frac{1}{2}}$ |
| 3391.294 | 150 | — | V E | 29478.84 | 8.81 | *b* $^5D^0_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3390.878 | 200 | — | V E | 29482.45 | 2.47 | *b* $^5D^0_{1\frac{1}{2}} - z\ ^5F_{1\frac{1}{2}}$ |
| 3390.498 | 30 | — | V E | 29485.76 | 5.76 | *b* $^5D^0_{3\frac{1}{2}} - z\ ^5F_{2\frac{1}{2}}$ |
| 3388.912 | 100 | — | V E | 29499.56 | 9.56 | *b* $^5D^0_{2\frac{1}{2}} - z\ ^5F_{1\frac{1}{2}}$ |
| 3388.065 | 40 | — | V E | 29506.93 | 6.89 | *b* $^5D^0_{4\frac{1}{2}} - 8i_{\frac{1}{2}}$ |
| 3380.515 | 300 | — | V E | 29572.83 | 2.78 | *b* $^5D^0_{1\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 3379.756 | 400 | — | V E | 29579.47 | 9.45 | *a* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3374.688 | 300 | — | V E | 29623.89 | 3.94 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^{[3]}P_{4\frac{1}{2}}$ |
| 3374.584 | 50 | — | V E | 29624.80 | 4.79 | *b* $^5D^0_{4\frac{1}{2}} - 9i_{\frac{1}{2}}$ |
| 3371.506 | 4 | — | V E | 29651.85 | 1.76 | $3^0i_{\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 3369.618 | 400 | — | V E | 29658.46 | 8.44<br>8.40 | *a* $^5D^0_{2\frac{1}{2}} - z\ ^5P_{2\frac{1}{2}}$<br>*b* $^5D^0_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3367.661 | 150 | — | V E | 29685.70 | 5.73 | *a* $^5D^0_{4\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3367.093 | 100 | — | V E | 29690.71 | 0.73 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3366.532 | 50 | — | V E | 29695.66 | 5.62 | *b* $^5D^0_{2\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 3365.591 | 400 | — | V E | 29703.96 | 4.00 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3363.974 | 30 | — | V E | 29718.23 | 8.30 | *a* $^{[3]}P^0_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3362.233 | 10000 | 150 | IV E | 29733.63 | 3.61 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3360.711 | 1000 | 12 | IV E | 29747.09 | 7.13 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3358.620 | 8000 | 150 | IV E | 29765.61 | 5.60 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3358.434 | 300 | — | V E | 29767.26 | 7.28 | *a* $^5S^0_{2\frac{1}{2}} - y\ ^{[3]}P_{2\frac{1}{2}}$ |
| 3356.513 | 80 | — | V E | 29784.29 | 4.28 | *a* $^5D^0_{3\frac{1}{2}} - y\ ^{[3]}P_{2\frac{1}{2}}$ |
| 3350.474 | 10000 | 150 | IV E | 29837.98 | 7.94 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^{[3]}D_{2\frac{1}{2}}$ |
| 3350.097 | 400 | — | V E | 29841.33 | 1.35 | *b* $^5D^0_{2\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 3348.718 | 5 | — | V E | 29853.62 | 3.60 | *a* $^5F^0_{3\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3345.985 | 2000 | 6 | IV E | 29878.00 | 8.01 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3345.585 | 2 | — | V E | 29881.58 | 1.59 | *b* $^5D^0_{4\frac{1}{2}} - x\ ^5P_{3\frac{1}{2}}$ |
| 3344.22 | 1 | — | V E | 29893.77 | 3.78 | *a* $^5D^0_{1\frac{1}{2}} - z\ ^5P_{1\frac{1}{2}}$ |
| 3340.14 | 15 | — | V E | 29930.29 | 0.19 | $3^0i_{\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3336.984 | 200 | — | V E | 29958.60 | 8.55 | *b* $^5D^0_{4\frac{1}{2}} - 9i_{\frac{1}{2}}$ |
| 3336.180 | 2500 | 20 | IV E | 29965.81 | 5.81 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3335.823 | 6*d*? | — | V E | 29969.02 | 9.21 | *a* $^5F^0_{3\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3332.133 | 1000 | — | V E | 30002.21 | 2.16 | *b* $^5D^0_{4\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 3331.383 | 4000 | 30 | IV E | 30008.96 | 8.94 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3329.345 | 400 | — | V E | 30027.33 | 7.32 | *b* $^5D^0_{3\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 3321.348 | 30 | — | V E | 30099.63 | 9.64 | *a* $^5D^0_{2\frac{1}{2}} - z\ ^5P_{1\frac{1}{2}}$ |
| 3320.438 | 300 | — | V E | 30107.88 | 7.85 | *b* $^5D^0_{3\frac{1}{2}} - x\ ^5P_{1\frac{1}{2}}$ |
| 3318.055 | 100 | — | V E | 30129.50 | 9.51 | *a* $^5D^0_{3\frac{1}{2}} - y\ ^{[3]}P_{2\frac{1}{2}}$ |
| 3315.590 | 400 | — | V E | 30151.90 | 1.85 | *a* $^5S^0_{2\frac{1}{2}} - y\ ^{[3]}P_{1\frac{1}{2}}$ |
| 3313.731 | 600 | — | V E | 30168.81 | 8.85 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^{[3]}P_{1\frac{1}{2}}$ |
| 3311.570 | 5 | — | V E | 30188.50 | 8.46 | *a* $^5F^0_{3\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3309.582 | 60 | — | V E | 30206.63 | 6.67 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^{[3]}P_{3\frac{1}{2}}$ |
| 3308.517 | 80 | — | V E | 30216.36 | 6.40 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3303.623 | 5 | — | V E | 30261.12 | 1.08 | *a* $^5F^0_{1\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 3300.976 | 60 | — | V E | 30285.38 | 5.42 | *b* $^5D^0_{4\frac{1}{2}} - x\ ^5P_{3\frac{1}{2}}$ |
| 3299.12 | 2 | — | V E | 30302.42 | 2.35 | *a* $^5F^0_{2\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 3296.668 | 30 | — | V E | 30324.96 | 4.98 | *a* $^5D^0_{1\frac{1}{2}} - z\ ^5P_{1\frac{1}{2}}$ |
| 3292.210 | 800 | — | V E | 30366.02 | 5.95 | *b* $^5D^0_{4\frac{1}{2}} - x\ ^5P_{4\frac{1}{2}}$ |
| 3291.008 | 6 | — | V E | 30377.11 | 7.16 | $2^0i_{\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 3289.150 | 100 | — | V E | 30394.27 | 4.26 | *b* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3287.192 | 40 | — | V E | 30412.37 | 2.41 | *a* $^5G^0_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3283.281 | 8*d*? | — | V E | 30448.60 | 8.41 | *b* $^5D^0_{2\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3282.305 | 400? | — | V E | 30457.65 | 7.63 | *a* $^5D^0_{1\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3281.607 | 200 | — | V E | 30464.13 | 4.13 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3279.529 | 200 | — | V E | 30483.43 | 3.46 | *a* $^5D^0_{\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 3278.038 | 12 | — | V E | 30497.30 | 7.42 | *a* $^{[3]}P^0_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$? |
| 3274.183 | 300 | — | V E | 30533.20 | 3.19 | *a* $^5D^0_{3\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3273.157 | 12 | — | V E | 30542.77 | 2.85 | $2^0i_{\frac{1}{2}} - 11s_{\frac{1}{2}}$ |
| 3270.515 | 100 | — | V E | 30567.44 | 7.45 | *a* $^5D^0_{\frac{1}{2}} - y\ ^5F_{\frac{1}{2}}$ |
| 3268.335 | 400 | — | V E | 30587.83 | 7.86 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5P_{4\frac{1}{2}}$ |
| 3268.20 | 5 | — | V E | 30589.10 | 9.08 | *a* $^5D^0_{1\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 3267.880 | 12 | — | V E | 30592.09 | 2.11 | $2^0i_{\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3264.137 | 60 | — | V E | 30627.17 | 7.18 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3263.373 | 125 | — | V E | 30634.34 | 4.38 | *b* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3262.774 | 8 | — | V E | 30639.96 | 9.92 | *b* $^5D^0_{1\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3262.515 | 80 | — | V E | 30642.40 | 2.36<br>2.34 | *b* $^5D^0_{4\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$<br>*b* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3260.59 | 3 | — | V E | 30660.49 | 0.47 | *a* $^{[3]}P^0_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3259.250 | 250 | — | V E | 30673.09 | 3.07 | *a* $^5D^0_{1\frac{1}{2}} - y\ ^5F_{\frac{1}{2}}$ |
| 3257.072 | 100 | — | V E | 30693.60 | 3.63 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 3256.423 | 1 | — | V E† | 30699.72 | 9.71 | *b* $^5D^0_{3\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 3255.819 | 150 | — | V E | 30705.41 | 5.43 | *a* $^5D^0_{3\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3255.276 | 6*d* | — | V E | 30710.54 | 0.66<br>0.70 | *a* $^5D^0_{4\frac{1}{2}} - 5i_{\frac{1}{2}}$<br>*b* $^5D^0_{1\frac{1}{2}} - z\ ^5D_{\frac{1}{2}}$ |
| 3252.743 | 30 | — | V E | 30734.45 | 4.53 | *a* $^5G^0_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 3250.187 | 300 | — | V E | 30758.62 | 8.63 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 3249.747 | 40 | — | V E | 30762.78 | 2.76 | *b* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{1\frac{1}{2}}$ |
| 3242.834 | 50 | — | V E | 30828.36 | 8.31 | *b* $^5D^0_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 3242.304 | 150 | — | V E | 30833.40 | 3.40 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 3238.621 | 300 | — | V E | 30868.46 | 8.48 | *a* $^5D^0_{3\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3236.106 | 150 | — | V E | 30892.45 | 2.48 | *b* $^5D^0_{4\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 3227.82 | 2 | — | V E | 30971.75 | 1.76 | *a* $^5G^0_{4\frac{1}{2}} - 10i_{\frac{1}{2}}$ |
| 3226.318 | 1000 | — | V E | 30986.17 | 6.12 | *b* $^5D^0_{3\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 3224.297 | 60 | — | V E | 31005.59 | 5.64 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3223.740 | 1000? | — | V E | 31010.95 | 0.94 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^5F_{2\frac{1}{2}}$ |
| 3223.534 | 6 | — | V E | 31012.93 | 2.96 | *a* $^5G^0_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 3212.274 | 50 | — | V E | 31121.63 | 1.67 | *a* $^{[3]}F^0_{3\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3211.570 | 50 | — | V E | 31128.46 | 8.55 | *c* $^5D^0_{1\frac{1}{2}} - 11s_{\frac{1}{2}}$ |
| 3210.34 | 2 | — | V E | 31140.38 | 0.37 | *a* $^5G^0_{3\frac{1}{2}} - 10i_{\frac{1}{2}}$ |
| 3209.817 | 6 | — | V E | 31145.46 | 5.51 | *a* $^{[3]}D^0_{3\frac{1}{2}} - y\ ^5P_{4\frac{1}{2}}$ |
| 3206.466 | 400 | — | V E | 31178.00 | 7.81 | *c* $^5D^0_{1\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3205.868 | 8 | — | V E | 31183.82 | 3.86 | *c* $^5D^0_{2\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 3200.454 | 60 | — | V E | 31236.57 | 6.62<br>6.48 | *c* $^5D^0_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$<br>(*a* $^5G^0_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$) |
| 3196.532 | 150 | — | V E | 31274.89 | 4.89 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3193.174 | 200 | — | V E | 31307.78 | 7.76 | *a* $^{[3]}F^0_{3\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3191.044 | 125 | — | V E | 31328.68 | 8.70 | *c* $^5D^0_{3\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 3187.795 | 12 | — | V E | 31360.61 | 0.56 | *c* $^5D^0_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3183.583 | 8 | — | V E | 31402.10 | 2.17 | *a* $^5G^0_{2\frac{1}{2}} - 11s_{\frac{1}{2}}$ |
| 3181.65 | 6 | — | V E? | 31421.17 | 1.09 | *c* $^5D^0_{2\frac{1}{2}} - 10i_{\frac{1}{2}}$ |
| 3178.60 | 6 | — | V E | 31451.32 | 1.43 | *a* $^5G^0_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3177.490 | 30 | — | V E | 31462.31 | 2.29 | *c* $^5D^0_{2\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 3176.32 | 4 | — | V E | 31473.90 | 3.85 | *c* $^5D^0_{4\frac{1}{2}} - 10i_{\frac{1}{2}}$ |
| 3172.169 | 30 | — | V E | 31515.08 | 5.05 | *c* $^5D^0_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 3171.09 | 125 | — | V E | 31525.81 | 5.81 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 3167.529 | 4 | — | V E | 31561.24 | 1.32 | *a* $^{[3]}P^0_{4\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |
| 3166.10 | 5 | — | V E | 31575.49 | 5.51 | *c* $^5D^0_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3162.764 | 25 | — | V E | 31608.79 | 8.84 | *a* $^{[3]}F^0_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3161.638 | 40 | — | V E | 31620.05 | 0.12 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 3161.369 | 2500 | 2 | IV E | 31622.74 | 2.71 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 3160.86 | 3 | — | V E | 31627.84 | 7.98 | *c* $^5D^0_{3\frac{1}{2}} - 11s_{\frac{1}{2}}$ |
| 3160.69 | 200* | — | V E | 31629.54 | 9.58 | *a* $^{[3]}D^0_{4\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |
| 3159.02 | 1 — | | | 31646.26 | 6.35 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3156.532 | 2000 | 4 | IV E | 31671.20 | 1.18 | *a* $^{[3]}D^0_{4\frac{1}{2}} - y\ ^5P_{4\frac{1}{2}}$ |
| 3155.937 | 5 | — | V E | 31677.17 | 7.24 | *c* $^5D^0_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 3146.878 | 250 | — | V E | 31768.36 | 8.32 | *b* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3145.516 | 800 | — | V E | 31782.11 | 2.05 | *b* $^5D^0_{3\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 3145.00 | 2500 | 2 | IV E | 31787.32 | 7.30 | *a* $^{[3]}D^0_{2\frac{1}{2}} - z\ ^5F_{2\frac{1}{2}}$ |
| 3143.131 | 400 | — | V E | 31806.23 | 6.21 | *a* $^5D^0_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3142.900 | 300 | — | V E | 31808.56 | 8.53 | *b* $^5D^0_{1\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 3138.094 | 80 | — | V E | 31857.28 | 7.29 | *a* $^{[3]}D^0_{4\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 3137.940 | 80 | — | V E | 31858.84 | 8.88 | *a* $^{[3]}F^0_{4\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 3135.034 | 200 | — | V E | 31888.37 | 8.38 | *a* $^{[3]}D^0_{3\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |
| 3133.852 | 1000 | — | V E | 31900.40 | 0.38 | *b* $^5D^0_{4\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 3133.094 | 150 | — | V E | 31908.11 | 8.16 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5P_{3\frac{1}{2}}$ |
| 3130.812 | 200 | — | V E | 31931.37 | 1.37 | *b* $^5D^0_{3\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3129.955 | 100 | — | V E | 31940.11 | 9.98 | *b* $^5D^0_{1\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 3129.696 | 80 | — | V E | 31942.76 | 2.73 | *a* $^5D^0_{1\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3128.560 | 200 | — | V E | 31954.36 | 4.29 | *b* $^5D^0_{2\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 3124.57 | 15 | — | V E | 31995.16 | 5.14 | *a* $^5D^0_{2\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 3124.250 | 150 | — | V E | 31998.44 | 8.35 | *a* $^{[3]}D^0_{3\frac{1}{2}} - z\ ^5F_{2\frac{1}{2}}$ |
| 3123.989 | 1000 | — | V E | 32001.11 | 1.04 | *a* $^{[3]}D^0_{4\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |

* Blend with arc line.

TABLE VII.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3121.760 | 80 | — | V E | 32023.95 | 3.97 | *b* $^8D^\circ_{1\frac{1}{2}} - y\ ^8F_{\frac{1}{2}}$ |
| 3120.181 | 125 | — | V E | 32040.16 | 0.15 | *b* $^8D^\circ_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 3119.941 | 800 | — | V E | 32042.63 | 2.64 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 3119.336 | 25 | — | V E | 32048.84 | 8.87 | *a* $^{10}D^\circ_{2\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 3119.08 | 60 | — | V E | 32051.47 | 1.48 | *a* $^{10}D^\circ_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3118.600 | 150 | — | V E | 32056.40 | 6.36 | *a* $^8D^\circ_{1\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 3117.974 | 40 | — | V E | 32062.84 | 2.82 | *b* $^8D^\circ_{2\frac{1}{2}} - y\ ^8F_{1\frac{1}{2}}$ |
| 3113.64 | 4 | — | V E | 32107.47 | 7.49 | *a* $^8S^\circ_{3\frac{1}{2}} - 5_{4\frac{1}{2}}$ |
| 3113.172 | 250 | — | V E | 32112.30 | 2.28 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3112.684 | 10 | — | V E | 32117.33 | 7.34 | *b* $^8D^\circ_{2\frac{1}{2}} - y\ ^8F_{2\frac{1}{2}}$ |
| 3111.995 | 20 | — | V E | 32124.44 | 4.49 | *a* $^8D^\circ_{2\frac{1}{2}} - 5_{4\frac{1}{2}}$ |
| 3109.948 | 12 | — | V E | 32145.58 | 5.57 | *a* $^{10}P^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3109.505 | 20 | — | V E | 32150.16 | 0.19 | *a* $^{10}D^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3108.360 | 150 | — | V E | 32162.00 | 1.98 | *a* $^8D^\circ_{1\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 3108.230 | 30 | — | V E | 32163.35 | 3.39 | *a* $^{10}F^\circ_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 3102.551 | 1000 | — | V E | 32222.22 | 2.21 | *b* $^8D^\circ_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 3101.911 | 250*d* | — | V E | 32228.86 | 8.75 | *a* $^{10}D^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 3101.407 | 50 | — | V E | 32234.10 | 4.14 | *b* $^8D^\circ_{3\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 3101.185 | 125 | — | V E | 32236.41 | 6.44 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3100.504 | 10000 | 30 | IV E | 32243.49 | 3.52 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 3098.899 | 300 | — | V E | 32260.19 | 0.16 | *a* $^{10}D^\circ_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 3098.644 | 800 | — | V E | 32262.85 | 2.85 | *a* $^{10}D^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3093.846 | 25 | — | V E | 32312.88 | 2.97 | *a* $^{10}D^\circ_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3092.058 | 150 | — | V E | 32331.56 | 1.53 | *a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 3089.954 | 400 | 5 | IV E | 32353.58 | 3.58 | *a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3089.204 | 30 | — | V E | 32361.43 | 1.51 | *a* $^{10}F^\circ_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 3085.621 | 60 | — | V E | 32399.00 | 9.07 | *a* $^{10}D^\circ_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3083.350 | 200 | — | V E | 32422.87 | 2.94 | *a* $^{10}D^\circ_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3081.993 | 8000 | 15 | IV E | 32437.14 | 7.15 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{4\frac{1}{2}}$ |
| 3077.077 | 800 | — | V E | 32488.98 | 9.04 | *a* $^8D^\circ_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 3076.925 | 2000 | — | V E | 32490.57 | 0.56 | *a* $^{10}D^\circ_{2\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 3076.188 | 10 | — | V E | 32498.35 | 8.42 | *a* $^{10}F^\circ_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 3075.422 | 30 | — | V E | 32506.45 | 6.49 | *a* $^{10}F^\circ_{3\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3072.565 | 1000 | — | V E | 32536.67 | 6.65 | *a* $^8D^\circ_{4\frac{1}{2}} - y\ ^8P_{3\frac{1}{2}}$ |
| 3068.643 | 4000 | 3 | IV E | 32578.26 | 8.25 | *a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 3063.536 | 10 | — | V E | 32632.56 | 2.59 | *a* $^{10}F^\circ_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 3059.555 | 8 | — | V E | 32675.02 | 5.13 | *a* $^8D^\circ_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 3058.119 | 80 | — | V E | 32690.37 | 0.37 | *a* $^{10}F^\circ_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3055.497 | 20 | — | V E | 32718.42 | 8.45 | *a* $^{10}F^\circ_{3\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 3053.570 | 600 | — | V E | 32739.06 | 9.08 | *a* $^8D^\circ_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 3052.511 | 50 | — | V E | 32750.42 | 0.45 | *a* $^{10}D^\circ_{2\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 3049.483 | 20 | — | V E | 32782.92 | 3.00 | *a* $^{10}F^\circ_{3\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 3040.34 | 150 | — | V E | 32881.54 | 1.61 | *a* $^{10}F^\circ_{4\frac{1}{2}} - 6_{5\frac{1}{2}}$ |
| 3034.051 | 8000 | 10 | IV E | 32949.62 | 9.71 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{2\frac{1}{2}}$ |
| 3032.845 | 10000 | 10 | IV E | 32962.77 | 2.82 | *a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^{10}P_{4\frac{1}{2}}$ |
| 3032.313 | 12 | — | V E | 32968.57 | 8.59 | *a* $^{10}F^\circ_{1\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 3030.00 | 2 | — | V E | 32093.76 | 3.66 | *a* $^{10}F^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3028.981 | 200 | — | V E | 33094.82 | 4.94 | *a* $^8D^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 3027.602 | 8000 | — | V E | 33019.82 | 9.88 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 3013.89 | 5 | — | V E | 33170.05 | 0.11 | *a* $^{10}F^\circ_{3\frac{1}{2}} - 9_{4\frac{1}{2}}$ |
| 3013.22 | 6 | — | V E | 33177.48 | 7.54 | *a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3012.190 | 600 | — | V E | 33188.75 | 8.82 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 3010.899 | 250 | — | V E | 33203.02 | 3.04 | *a* $^8S^\circ_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 3010.129 | 8000 | 5 | IV E | 33211.59 | 1.52 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{2\frac{1}{2}}$ |
| 3009.650 | 150 | — | V E | 33216.80 | 6.90 | *a* $^8D^\circ_{3\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 3009.366 | 60 | — | V E | 33219.94 | 0.04 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 3003.583 | 150 | — | V E | 33283.90 | 3.99 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 3002.710 | 60 | — | V E | 33293.57 | 3.63 | *b* $^8D^\circ_{1\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 3002.197 | 50 | — | V E | 33299.26 | 9.33 | *b* $^8D^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 2999.045 | 8000 | — | V E | 33334.26 | 4.28 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^{10}P_{4\frac{1}{2}}$ |
| 2993.038 | 500 | — | V E | 33401.16 | 1.16 | *a* $^8S^\circ_{3\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 2991.520 | 150 | — | V E | 33418.10 | 8.16 | *a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 2987.074 | 80 | — | V E | 33467.84 | 7.90 | *a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2985.521 | 100 | — | V E | 33485.25 | 5.30 | *b* $^8D^\circ_{2\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 2983.060 | 60 | — | V E | 33512.87 | 2.88 | *b* $^8D^\circ_{1\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 2980.154 | 6000 | — | V E | 33545.55 | 5.55 | *a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^{10}P_{3\frac{1}{2}}$ |
| 2975.110 | 30 | — | V E | 33602.42 | 2.44 | *b* $^8D^\circ_{3\frac{1}{2}} - y\ ^8P_{2\frac{1}{2}}$ |
| 2972.742 | 150 | — | V E | 33629.19 | 9.22 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 2672.17 | 100 | — | V E | 33635.66 | 5.72 | *b* $^8D^\circ_{2\frac{1}{2}} - y\ ^8P_{1\frac{1}{2}}$ |
| 2969.267 | 50 | — | V E | 33668.54 | 8.56 | *a* $^8D^\circ_{4\frac{1}{2}} - 9_{5\frac{1}{2}}$ |
| 2965.428 | 400 | — | V E | 33712.13 | 2.17 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 2960.926 | 500 | — | V E | 33763.38 | 3.39 | *a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 2954.538 | 30 | — | V E | 33836.38 | 6.36 | *a* $^{10}F^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2951.278 | 25 | — | V E | 33873.75 | 3.86 | *a* $^8D^\circ_{4\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 2948.01 | 250 | — | V E | 33911.30 | 1.27 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2947.795 | 200 | — | V E | 33913.77 | 3.80 | *a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 2941.30 | 30 | — | V E | 33988.66 | 8.73 | *a* $^8D^\circ_{1\frac{1}{2}} - y\ ^8D_{2\frac{1}{2}}$ |
| 2935.336 | 15 | — | V E | 34057.72 | 7.74 | *a* $^8D^\circ_{4\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 2932.927 | 100 | — | V E | 34085.69 | 5.82 | *a* $^8D^\circ_{4\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 2931.06 | 15 | — | V E | 34107.39 | 7.44 | *a* $^{10}F^\circ_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2928.336 | 300 | — | V E | 34139.12 | 9.14 | *a* $^8D^\circ_{1\frac{1}{2}} - y\ ^8D_{1\frac{1}{2}}$ |
| 2927.851 | 10 | — | V E | 34144.78 | 4.81 | *a* $^{10}F^\circ_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2925.864 | 15 | — | V E | 34167.96 | 8.09 | *a* $^{10}F^\circ_{1\frac{1}{2}} - y\ ^8F_{1\frac{1}{2}}$ |
| 2923.322 | 800 | — | V E | 34197.67 | 7.68 | *a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 2915.477 | 8 | — | V E | 34289.69 | 9.72 | *a* $^8S^\circ_{3\frac{1}{2}} - 6_{5\frac{1}{2}}$ |
| 2914.03 | 6 | — | V E | 34306.72 | 6.72 | *a* $^8D^\circ_{3\frac{1}{2}} - 6_{5\frac{1}{2}}$ |
| 2913.080 | 300 | — | V E | 34317.90 | 7.91 | *a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8P_{3\frac{1}{2}}$ |
| 2910.526 | 1500 | — | V E | 34348.02 | 8.10 | *a* $^8D^\circ_{4\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2906.260 | 125 | — | V E | 34398.43 | 8.44 | *a* $^{10}F^\circ_{4\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2905.973 | 80 | — | V E | 34401.83 | 1.77 | *a* $^8S^\circ_{3\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 2905.307 | 4000 | — | V E | 34409.72 | 9.72 | *a* $^8D^\circ_{3\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2904.79 | 10 | — | V E | 34415.84 | 5.89 | *a* $^{10}F^\circ_{2\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2904.548 | 40 | — | V E | 34418.71 | 8.77 | *a* $^8D^\circ_{3\frac{1}{2}} - 7_{4\frac{1}{2}}$ |
| 2895.528 | 300 | — | V E | 34525.93 | 5.89 | *a* $^{10}D^\circ_{3\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 2894.290 | 125 | — | V E | 34540.69 | 0.64 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 2890.913 | 50 | — | V E | 34581.03 | 1.09 | *a* $^8D^\circ_{4\frac{1}{2}} - z\ ^8F_{5\frac{1}{2}}$ |
| 2890.530 | 200 | — | V E | 34585.62 | 5.65 | *a* $^8S^\circ_{3\frac{1}{2}} - z\ ^8F_{4\frac{1}{2}}$ |
| 2889.21 | 10 | — | V E | 34601.42 | 1.48 | *a* $^{10}F^\circ_{1\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2889.11 | 10 | — | V E | 34602.61 | 2.65 | *a* $^8D^\circ_{2\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2888.18 | 80 | — | V E | 34613.76 | 3.73 | *a* $^8S^\circ_{3\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 2886.77 | 8 | — | V E | 34630.66 | 0.73 | *a* $^8D^\circ_{2\frac{1}{2}} - 8_{4\frac{1}{2}}$ |
| 2882.257 | 50 | — | V E | 34684.88 | 4.85 | *a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 2882.130 | 150 | — | V E | 34686.41 | 6.37 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 2881.329 | 4000 | — | V E | 34696.05 | 6.13 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 2875.460 | 50 | — | V E | 34766.87 | 6.90 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2871.754 | 200 | — | V E | 34811.73 | 1.72 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 2866.458 | 80 | — | V E | 34876.04 | 6.01<br>5.99 | *a* $^8S^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$<br>(*a* $^{10}F^\circ_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$) |
| 2865.48 | 3 | — | V E | 34887.95 | 7.92 | *a* $^{10}F^\circ_{3\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 2865.063 | 500 | — | V E | 34893.03 | 3.01 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2862.475 | 800 | — | V E | 34924.57 | 4.97 | (*a* $^{10}F^\circ_{4\frac{1}{2}} - z\ ^8D_{3\frac{1}{2}}$) |
| 2859.776 | 150 | — | V E | 34957.53 | 7.45 | *a* $^{10}F^\circ_{3\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 2856.520 | 300 | — | V E | 34997.38 | 7.31 | *a* $^{10}F^\circ_{1\frac{1}{2}} - z\ ^8P_{2\frac{1}{2}}$ |
| 2841.329 | 600 | — | V E | 35184.48 | 4.46 | *a* $^8S^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2840.231 | 3000 | — | V E | 35198.06 | 8.11 | *a* $^8D^\circ_{4\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 2839.97 | 12 | — | V E | 35201.31 | 1.46 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2836.996 | 500 | — | V E | 35238.21 | 8.24 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2833.746 | 1500 | — | V E | 35278.62 | 8.64 | *a* $^8D^\circ_{4\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2821.34 | 4 | — | V E | 35433.74 | 3.77 | *a* $^{10}F^\circ_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 2816.996 | 80 | — | V E | 35488.38 | 8.34 | *a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 2812.374 | 15 | — | V E | 35546.71 | 6.69 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{3\frac{1}{2}}$ |
| 2810.930 | 800 | — | V E | 35564.96 | 5.05 | *a* $^8D^\circ_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 2809.720 | 5000 | — | V E | 35580.28 | 0.29 | *a* $^8S^\circ_{3\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 2809.31 | 3 | — | V E | 35585.47 | 5.47 | *a* $^{10}F^\circ_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 2808.380 | 150 | — | V E | 35597.25 | 7.29 | *a* $^8D^\circ_{3\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 2798.260 | 150 | — | V E | 35725.98 | 6.02 | *a* $^8S^\circ_{3\frac{1}{2}} - x\ ^8P_{2\frac{1}{2}}$ |
| 2796.932 | 6000 | — | V E | 35742.95 | 3.02 | *a* $^8D^\circ_{3\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 2796.667 | 30 | — | V E | 35746.33 | 6.46 | *a* $^8D^\circ_{3\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 2794.661 | 100 | — | V E | 35771.99 | 2.03 | *a* $^8D^\circ_{1\frac{1}{2}} - z\ ^8F_{2\frac{1}{2}}$ |
| 2792.07 | 50 | — | V E | 35805.18 | 5.17 | *a* $^8D^\circ_{4\frac{1}{2}} - z\ ^8D_{4\frac{1}{2}}$ |
| 2791.963 | 1500 | — | V E | 35806.56 | 6.55 | *a* $^8S^\circ_{3\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2790.644 | 50 | — | V E | 35823.48 | 3.55 | *a* $^8D^\circ_{3\frac{1}{2}} - x\ ^8P_{4\frac{1}{2}}$ |
| 2790.300 | 80 | — | V E | 35827.90 | 7.92 | *a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^8D_{4\frac{1}{2}}$ |
| 2782.206 | 50 | — | V E | 35932.12 | 2.22 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 2782.15 | 6 | — | V E | 35932.84 | 2.87 | *a* $^{10}F^\circ_{4\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |
| 2781.402 | 3000 | — | V E | 35942.50 | 2.52 | *a* $^8D^\circ_{3\frac{1}{2}} - x\ ^8P_{3\frac{1}{2}}$ |
| 2781.29 | 60 | — | V E | 35943.96 | 4.03<br>4.15 | *a* $^{10}F^\circ_{1\frac{1}{2}} - z\ ^8D_{2\frac{1}{2}}$<br>*a* $^8D^\circ_{2\frac{1}{2}} - y\ ^8F_{3\frac{1}{2}}$ |
| 2779.140 | 50 | — | V E | 35971.76 | 1.80 | *a* $^8D^\circ_{1\frac{1}{2}} - z\ ^8F_{1\frac{1}{2}}$ |
| 2770.983 | 80*d* | — | V E | 36077.64 | 7.55<br>7.96 | *a* $^8D^\circ_{1\frac{1}{2}} - z\ ^8F_{\frac{1}{2}}$<br>*a* $^{10}D^\circ_{4\frac{1}{2}} - y\ ^8D_{3\frac{1}{2}}$ |
| 2770.503 | 20 | — | V E | 36083.90 | 3.92 | *a* $^8D^\circ_{3\frac{1}{2}} - y\ ^8F_{4\frac{1}{2}}$ |

TABLE VII.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 2770.173 | 1200 | — | V E | 36088.19 | 8.25 | *a* $^5D^o_{2\frac{1}{2}} - x\ ^5P_{3\frac{1}{2}}$ |
| 2769.808 | 1500 | — | V E | 36092.95 | 2.96 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 2768.507 | 200 | — | V E | 36109.91 | 9.96 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$ |
| 2766.55 | 2 | — | V E | 36135.45 | 5.23 | *a* $^{10}F^o_{1\frac{1}{2}} - z\ ^5D_{\frac{1}{2}}$ |
| 2764.076 | 3000 | — | V E | 36167.79 | 7.86 | *a* $^5D^o_{1\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 2757.34 | 1 | — | V E | 36256.14 | 6.12 | *a* $^5F^o_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2751.51 | 6 | — | V E | 36332.96 | 3.08 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 2750.216 | 100 | — | V E | 36350.05 | 0.08 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 2747.545 | 25 | — | V E | 36385.39 | 5.47 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5D_{4\frac{1}{2}}$ |
| 2743.35 | 20*d* | — | V E | 36441.02 | 1.10<br>0.49 | *a* $^{10}F^o_{2\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$<br>*a* $^5F^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2736.90 | 2 | — | V E | 36526.90 | 7.01 | *a* $^5S^o_{2\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 2735.63 | 3 | — | V E | 36543.85 | 4.01 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 2732.67 | 4 | — | V E | 36583.44 | 3.59 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 2730.446 | 3 | — | V E | 36613.23 | 3.34 | *a* $^{10}F^o_{3\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 2730.103 | 6 | — | V E | 36617.83 | 7.94 | *a* $^{10}D^o_{2\frac{1}{2}} - z\ ^5F_{3\frac{1}{2}}$ |
| 2724.35 | 1 | — | V E | 36695.15 | 5.31 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{2\frac{1}{2}}$ |
| 2723.16 | 8 | — | V E | 36711.19 | 1.23 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5D_{3\frac{1}{2}}$ |
| 2715.630 | 12 | — | V E | 36812.97 | 3.07 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5F_{5\frac{1}{2}}$ |
| 2710.37 | 3 | — | V E | 36884.41 | 4.42 | *a* $^{10}F^o_{2\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 2710.01 | 6*d* | — | V E | 36889.31 | 9.24 | *a* $^5D^o_{2\frac{1}{2}} - z\ ^5D_{3\frac{1}{2}}$ |
| 2705.360 | 50 | — | V E | 36952.71 | 2.84 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 2702.21 | 1 | — | V E | 36995.79 | 5.81 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5D_{1\frac{1}{2}}$ |
| 2698.44 | 5 | — | E | 37047.48 | 7.47 | *a* $^{10}F^o_{3\frac{1}{2}} - y\ ^5F_{5\frac{1}{2}}$ |
| 2692.80 | 40 | | E | 37125.06 | 5.08 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5F_{5\frac{1}{2}}$ |
| 2686.46 | 6 | | E | 37212.67 | 2.74 | *a* $^{10}D^o_{4\frac{1}{2}} - \quad 7_{4\frac{1}{2}}$ |
| 2676.55 | 2 | | E | 37350.44 | 0.69 | *a* $^{10}D^o_{3\frac{1}{2}} - \quad 9_{4\frac{1}{2}}$ |
| 2675.56 | 2 | | E | 37364.27 | 4.51 | *a* $^{10}F^o_{1\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 2673.26 | 2 | | E | 37396.41 | 6.62 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^5F_{4\frac{1}{2}}$ |
| 2669.53 | 6 | | E | 37448.66 | 8.50 | *a* $^{10}F^o_{1\frac{1}{2}} - y\ ^5F_{\frac{1}{2}}$ |
| 2667.24 | 30 | | E | 37480.81 | 0.75 | *a* $^5S^o_{2\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 2661.50 | 300 | | E | 37561.64 | 1.57 | *a* $^{10}P^o_{2\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2655.04 | 25 | | E | 37653.02 | 2.99 | *a* $^5S^o_{2\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 2646.41 | 4 | | E | 37775.80 | 5.89 | *a* $^{10}F^o_{4\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |
| 2643.60 | 8 | | E | 37815.95 | 6.04 | *a* $^5S^o_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 2642.41 | 10 | | E | 37832.98 | 3.04 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$ |
| 2636.35 | 20 | | E | 37919.94 | 9.97 | *a* $^{10}D^o_{4\frac{1}{2}} - z\ ^5F_{5\frac{1}{2}}$ |
| 2631.69 | 50 | | E | 37987.09 | 6.92 | *a* $^{10}P^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2629.73 | 20 | | E | 38015.39 | 5.22 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 2624.46 | 15 | | E | 38091.73 | 1.85 | *a* $^{10}D^o_{4\frac{1}{2}} - x\ ^5P_{4\frac{1}{2}}$ |
| 2620.82 | 3 | | E | 38144.63 | 4.35 | *a* $^{10}F^o_{2\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 2618.51 | 15 | | E | 38178.27 | 8.27 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 2612.81 | 6 | | E | 38261.56 | 1.49 | *a* $^{10}F^o_{3\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 2612.55 | 30 | | E | 38265.37 | 5.35 | *a* $^{10}P^o_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2609.51 | 10 | | E | 38309.94 | 9.72 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5F_{1\frac{1}{2}}$ |
| 2604.87 | 5 | | E | 38378.18 | 8.26 | *a* $^{10}D^o_{3\frac{1}{2}} - z\ ^5D_{4\frac{1}{2}}$? |
| 2602.32 | 2 | | E | 38415.78 | 5.43 | *a* $^{10}F^o_{2\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 2599.74 | 5 | | E | 38453.90 | 4.03 | *a* $^{10}P^o_{2\frac{1}{2}} - w\ ^5P_{1\frac{1}{2}}$ |
| 2594.13 | 50 | | E | 38537.06 | 6.99 | *a* $^{10}D^o_{4\frac{1}{2}} - x\ ^5P_{3\frac{1}{2}}$ |
| 2586.13 | 300 | | E | 38656.26 | 6.09 | *a* $^5D^o_{4\frac{1}{2}} - y\ ^5P_{3\frac{1}{2}}$ |
| 2583.29 | 10 | | E | 38698.75 | 9.17 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{1\frac{1}{2}}$? |
| 2581.05 | 60 | | E | 38732.34 | 2.46 | *a* $^{10}P^o_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2580.26 | 8 | | E | 38744.19 | 4.57 | *a* $^5D^o_{1\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2579.75 | 8 | | E | 38751.85 | 1.82 | *a* $^{10}F^o_{3\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 2579.03 | 80 | | E | 38762.67 | 2.72 | *a* $^{10}D^o_{3\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 2574.03 | 200 | | E | 38837.96 | 7.99 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5F_{2\frac{1}{2}}$ |
| 2569.01 | 10 | | E | 38913.85 | 4.12 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2567.26 | 60 | | E | 38940.37 | 0.47 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{1\frac{1}{2}}$ |
| 2565.81 | 80 | | E | 38962.38 | 2.25 | *a* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2564.07 | 40 | | E | 38988.82 | 8.98 | *a* $^{10}D^o_{3\frac{1}{2}} - x\ ^5P_{4\frac{1}{2}}$ |
| 2561.72 | 30 | | E | 39024.58 | 4.53 | *a* $^{10}D^o_{2\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 2553.17 | 15 | | E | 39155.26 | 5.42 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2552.19 | 60 | | E | 39170.29 | 0.26 | *a* $^{10}D^o_{2\frac{1}{2}} - x\ ^5P_{2\frac{1}{2}}$ |
| 2551.30 | 200 | | E | 39183.95 | 4.00 | *a* $^5S^o_{2\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 2550.18 | 800 | | E | 39201.16 | 1.00 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 2547.61 | 125 | | E | 39240.70 | 0.68 | *a* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2543.68 | 1000 | | E | 39301.32 | 1.14 | *a* $^5S^o_{2\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 2520.47 | 80 | | E | 39663.21 | 3.37 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5P_{2\frac{1}{2}}$ |
| 2506.61 | 80 | | E | 39882.51 | 2.62 | *a* $^5D^o_{2\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 2504.83 | 200 | | E | 39910.84 | 0.90 | *b* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2501.61 | 100 | | E | 39962.21 | 2.16 | *b* $^5D^o_{2\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2499.04 | 500 | | E | 40003.31 | 3.36 | *b* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2496.35 | 600 | | E | 40046.41 | 6.21 | *b* $^5D^o_{1\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2493.29 | 600 | | E | 40095.55 | 5.47 | *b* $^5D^o_{1\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2492.52 | 25 | | E | 40107.94 | 7.96 | *a* $^5D^o_{1\frac{1}{2}} - y\ ^5P_{1\frac{1}{2}}$ |
| 2490.01 | 100 | | E | 40148.36 | 8.13 | *b* $^5D^o_{2\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2488.72 | 2500 | | E | 40169.17 | 9.00<br>9.05 | *b* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$<br>*b* $^5D^o_{2\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2487.46 | 2000 | | E | 40189.52 | 9.33 | *b* $^5D^o_{3\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2485.67 | 1000 | | E | 40218.46 | 8.31 | *b* $^5D^o_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2481.16 | 10 | | E | 40291.56 | 1.72 | *a* $^{10}D^o_{4\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 2477.27 | 200 | | E | 40354.82 | 5.02 | *b* $^5D^o_{2\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2474.25 | 100 | | E | 40404.08 | 4.28 | *b* $^5D^o_{3\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2474.12 | 200 | | E | 40406.19 | 6.23 | *b* $^5D^o_{4\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2471.58 | 2000 | | E | 40447.72 | 7.43 | *b* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2470.61 | 2 | | E? | 40463.60 | 3.96 | *a* $^{10}D^o_{4\frac{1}{2}} - y\ ^5F_{3\frac{1}{2}}$? |
| 2468.22 | 5000 | | E | 40502.77 | 2.76 | *b* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2458.47 | 15 | | E | 40663.39 | 3.18 | *a* $^{10}D^o_{2\frac{1}{2}} - y\ ^5F_{4\frac{1}{2}}$ |
| 2286.88 | 150 | | E | 43714.18 | 4.32 | *a* $^{10}F^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2261.09 | 3000 | | E | 44212.74 | 2.77 | *a* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2217.52 | 600 | | E | 45081.34 | 1.69 | *a* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2205.90 | 60 | | E | 45318.79 | 8.92 | *a* $^5D^o_{4\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2203.92 | 800 | | E | 45359.50 | 0.12 | *a* $^5D^o_{4\frac{1}{2}} - w\ ^5P_{3\frac{1}{2}}$ |
| 2191.84 | 5000 | | E | 45609.47 | 9.60 | *a* $^5S^o_{2\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2191.03 | 3000 | | E | 45626.33 | 6.60 | *a* $^5D^o_{3\frac{1}{2}} - w\ ^5P_{4\frac{1}{2}}$ |
| 2180.50 | 300 | | E | 45846.64 | 6.83 | *a* $^5S^o_{2\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2179.69 | 600 | | E | 45863.67 | 3.83 | *a* $^5D^o_{2\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2178.53 | 3000 | | E | 45888.06 | 8.03 | *a* $^5S^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2177.74 | 4000 | | E | 45904.73 | 5.03 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2170.69 | 2500 | | E | 46053.80 | 3.72 | *a* $^5S^o_{2\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2169.89 | 600 | | E | 46070.78 | 0.72 | *a* $^5D^o_{2\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2168.37 | 2500 | | E | 46103.07 | 2.98 | *a* $^5S^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2167.57 | 500 | | E | 46120.09 | 9.98 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2163.39 | 6 | | E | 46209.19 | 9.06 | *a* $^5D^o_{2\frac{1}{2}} - \quad 10_{3\frac{1}{2}}$ |
| 2161.45 | 125 | | E | 46250.66 | 0.26 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2153.74 | 100 | | E | 46416.21 | 5.95 | *a* $^5D^o_{2\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2151.47 | 80 | | E | 46465.18 | 5.21 | *a* $^5D^o_{2\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |
| 2143.35 | 60 | | E | 46641.18 | 1.29 | *a* $^5D^o_{1\frac{1}{2}} - \quad 11_{2\frac{1}{2}}$ |
| 2141.10 | 50 | | E | 46690.19 | 0.55 | *a* $^5D^o_{1\frac{1}{2}} - w\ ^5P_{2\frac{1}{2}}$ |

TABLE VIII. Terms and levels of Gd I.

| Config. | Desig. | Level | Interval |
|---|---|---|---|
| $4f^7\ 6s^2\ 5d$ | $a\ ^7D^\circ_5$ | 6976.49 | |
| | $a\ ^7D^\circ_4$ | 7234.90 | −258.41 |
| | $a\ ^7D^\circ_3$ | 7426.69 | −191.79 |
| | $a\ ^7D^\circ_2$ | 7562.45 | −135.76 |
| | $a\ ^7D^\circ_1$ | 7653.95 | − 91.50 |
| $4f^7\ 6s^2(a\ ^8S^\circ)7s$ | $e\ ^9S^\circ_4$ | 34719.07 | |
| $4f^7\ 6s^2\ 5d$ | $a\ ^9D^\circ_6$ | 1719.06 | |
| | $a\ ^9D^\circ_5$ | 999.11 | 719.95 |
| | $a\ ^9D^\circ_4$ | 532.98 | 466.13 |
| | $a\ ^9D^\circ_3$ | 215.13 | 317.85 |
| | $a\ ^9D^\circ_2$ | 0.00 | 215.13 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)7s$ | $e\ ^9D^\circ_6$ | 34754.96 | |
| | $e\ ^9D^\circ_5$ | 34044.24 | 710.72 |
| | $e\ ^9D^\circ_4$ | 33534.66 | 509.58 |
| | $e\ ^9D^\circ_3$ | 33195.25 | 339.41 |
| | $e\ ^9D^\circ_2$ | 32957.72 | 237.53 |
| $4f^7\ 6s\ 5d^2$ | $a\ ^9F^\circ_7$ | 12486.60 | |
| | $a\ ^9F^\circ_6$ | 11830.45 | 656.15 |
| | $a\ ^9F^\circ_5$ | 11296.52 | 533.93 |
| | $a\ ^9F^\circ_4$ | 10883.56 | 412.96 |
| | $a\ ^9F^\circ_3$ | 10576.47 | 307.09 |
| | $a\ ^9F^\circ_2$ | 10359.94 | 216.53 |
| | $a\ ^9F^\circ_1$ | 10222.26 | 137.68 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)7s$ | $e\ ^{11}D^\circ_7$ | 33804.45 | |
| | $e\ ^{11}D^\circ_6$ | 33061.49 | 742.96 |
| | $e\ ^{11}D^\circ_5$ | 32547.56 | 513.93 |
| | $e\ ^{11}D^\circ_4$ | 32176.40 | 371.16 |
| | $e\ ^{11}D^\circ_3$ | 31906.96 | 269.44 |
| $4f^7\ 6s\ 5d^2$ | $a\ ^{11}F^\circ_8$ | 8498.50 | |
| | $a\ ^{11}F^\circ_7$ | 7947.35 | 551.15 |
| | $a\ ^{11}F^\circ_6$ | 7480.40 | 466.95 |
| | $a\ ^{11}F^\circ_5$ | 7103.46 | 376.94 |
| | $a\ ^{11}F^\circ_4$ | 6786.24 | 317.22 |
| | $a\ ^{11}F^\circ_3$ | 6550.44 | 235.80 |
| | $a\ ^{11}F^\circ_2$ | 6378.17 | 172.27 |
| $4f^7\ 6s^2(a\ ^8S^\circ)6p$? | $z\ ^7P_4$? | 18509.18 | |
| | $z\ ^7P_3$ | | |
| | $z\ ^7P_2$ | | |
| $4f^7\ 6s\ 5d\ 6p$ | $x\ ^7P_4$ | 32785.18 | |
| | $x\ ^7P_3$ | 33704.67 | −919.49 |
| | $x\ ^7P_2$ | 34147.37 | −442.70 |
| | $z\ ^7D_5$ | 19700.60 | |
| | $z\ ^7D_4$ | 19507.32 | 193.28 |
| | $z\ ^7D_3$ | 19399.87 | 107.45 |
| | $z\ ^7D_2$ | 19330.63 | 69.24 |
| | $z\ ^7D_1$ | 19285.49 | 45.14 |
| $4f^7\ 6s\ 5d\ 6p$ | $x\ ^7D_5$ | 31457.22 | |
| | $x\ ^7D_4$ | 31859.31 | −402.09 |
| | $x\ ^7D_3$ | 32133.16 | −273.85 |
| | $x\ ^7D_2$ | 32336.08 | −202.92 |
| | $x\ ^7D_1$ | 32356.13 | − 20.05 |
| $4f^7\ 6s\ 5d\ 6p$ | $x\ ^7F_6$ | 31794.80 | |
| | $x\ ^7F_5$ | 32020.38 | −225.58 |
| | $x\ ^7F_4$ | 31847.51 | 172.87 |
| | $x\ ^7F_3$ | 31999.82 | −152.31 |
| | $x\ ^7F_2$ | 32149.55 | −149.73 |
| | $x\ ^7F_1$ | 32251.80 | −102.25 |
| | $x\ ^7F_0$ | 32341.16 | − 89.36 |
| $4f^7\ 6s^2(a\ ^8S^\circ)6p$ | $z\ ^9P_5$ | 15665.39 | |
| | $z\ ^9P_4$ | 13926.28 | 1739.11 |
| | $z\ ^9P_3$ | 13433.82 | 492.46 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $y\ ^9P_5$ | 21905.37 | |
| | $y\ ^9P_4$ | 21674.76 | 230.61 |
| | $y\ ^9P_3$ | 21543.14 | 131.62 |
| | $x\ ^9P_5$ | 27731.23 | |
| | $x\ ^9P_4$ | 27425.30 | 305.93 |
| | $x\ ^9P_3$ | 27135.75 | 289.55 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $z\ ^9D_6$ | 23229.36 | |
| | $z\ ^9D_5$ | 23196.44 | 32.92 |
| | $z\ ^9D_4$ | 22820.91 | 375.53 |
| | $z\ ^9D_3$ | 22563.85 | 257.06 |
| | $z\ ^9D_2$ | 22334.52 | 229.33 |
| | $y\ ^9D_6$ | 25661.35 | |
| | $y\ ^9D_5$ | 25043.65 | 617.70 |
| | $y\ ^9D_4$ | 24849.50 | 194.15 |
| | $y\ ^9D_3$ | 24714.84 | 134.66 |
| | $y\ ^9D_2$ | 24655.65 | 59.19 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $x\ ^9D_6$ | 32966.88 | |
| | $x\ ^9D_5$ | 32585.16 | 381.72 |
| | $x\ ^9D_4$ | 32206.89 | 378.27 |
| | $x\ ^9D_3$ | 31869.15 | 337.74 |
| | $x\ ^9D_2$ | 31865.27 | 3.88 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $z\ ^9F_7$ | 20434.13 | |
| | $z\ ^9F_6$ | 18070.26 | 2363.87 |
| | $z\ ^9F_5$ | 18083.64 | − 13.38 |
| | $z\ ^9F_4$ | 17930.52 | 153.12 |
| | $z\ ^9F_3$ | 17795.25 | 135.27 |
| | $z\ ^9F_2$ | 17750.00 | 45.25 |
| | $z\ ^9F_1$ | 17510.00 | 240.00 |
| | $y\ ^9F_7$ | 25376.34 | |
| | $y\ ^9F_6$ | 24430.45 | 945.89 |
| | $y\ ^9F_5$ | 23999.92 | 430.53 |
| | $y\ ^9F_4$ | 23644.19 | 355.73 |
| | $y\ ^9F_3$ | 23389.80 | 254.39 |
| | $y\ ^9F_2$ | 23215.07 | 174.73 |
| | $y\ ^9F_1$ | 23103.64 | 111.43 |
| | $x\ ^9F_7$ | 26145.89 | |
| | $x\ ^9F_6$ | 26568.31 | −422.42 |
| | $x\ ^9F_5$ | 26615.07 | − 46.76 |
| | $x\ ^9F_4$ | 26866.41 | −251.34 |
| | $x\ ^9F_3$ | 27041.79 | −175.38 |
| | $x\ ^9F_2$ | 27118.76 | − 76.97 |
| | $x\ ^9F_1$ | 27129.27 | − 10.51 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $w\ ^9F_7$ | 32729.57 | |
| | $w\ ^9F_6$ | 32091.82 | 637.75 |
| | $w\ ^9F_5$ | 31778.02 | 313.80 |
| | $w\ ^9F_4$ | 31135.86 | 642.16 |
| | $w\ ^9F_3$ | 30881.70 | 254.16 |
| | $w\ ^9F_2$ | 30694.94 | 186.76 |
| | $w\ ^9F_1$ | 30555.90 | 139.04 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $z\ ^9G_8$ | 31171.70 | |
| | $z\ ^9G_7$ | 30505.42 | 666.28 |
| | $z\ ^9G_6$ | 30007.35 | 498.07 |
| | $z\ ^9G_5$ | 29628.41 | 378.94 |
| | $z\ ^9G_4$ | 29501.70 | 126.71 |
| | $z\ ^9G_3$ | 29125.89 | 375.81 |
| | $z\ ^9G_2$ | 29005.68 | 120.21 |
| | $z\ ^9G_1$ | 28984.73 | 20.95 |
| | $z\ ^9G_0$ | 28836.89 | 147.84 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $z\ ^{11}P_6$ | 20160.14 | |
| | $z\ ^{11}P_5$ | 19525.37 | 634.77 |
| | $z\ ^{11}P_4$ | 16824.60 | 700.77 |

TABLE VIII.—*Continued.*

| Config. | Desig. | Level | Interval |
|---|---|---|---|
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $z\ ^{11}D_7$ | 18014.46 | |
| | $z\ ^{11}D_6$ | 17318.94 | 695.52 |
| | $z\ ^{11}D_5$ | 16885.76 | 433.18 |
| | $z\ ^{11}D_4$ | 16196.04 | 689.72 |
| | $z\ ^{11}D_3$ | 16061.30 | 134.74 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $y\ ^{11}D_7$ | 31146.51 | |
| | $y\ ^{11}D_6$ | 30652.08 | 494.43 |
| | $y\ ^{11}D_5$ | 30242.33 | 409.75 |
| | $y\ ^{11}D_4$ | 29876.69 | 365.64 |
| | $y\ ^{11}D_3$ | 29631.33 | 245.36 |
| $4f^7\ 6s\ 5d(a\ ^{10}D^\circ)6p$ | $z\ ^{11}F_8$ | 17910.00 | |
| | $z\ ^{11}F_7$ | 16774.97 | 1135.03 |
| | $z\ ^{11}F_6$ | 15852.22 | 922.75 |
| | $z\ ^{11}F_5$ | 15173.98 | 678.24 |
| | $z\ ^{11}F_4$ | 14669.14 | 504.84 |
| | $z\ ^{11}F_3$ | 14298.27 | 370.87 |
| | $z\ ^{11}F_2$ | 14036.00 | 262.27 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $y\ ^{11}F_8$ | 29794.82 | |
| | $y\ ^{11}F_7$ | 29293.68 | 501.14 |
| | $y\ ^{11}F_6$ | 28841.73 | 451.95 |
| | $y\ ^{11}F_5$ | 28451.03 | 390.70 |
| | $y\ ^{11}F_4$ | 28111.72 | 339.31 |
| | $y\ ^{11}F_3$ | 27861.17 | 250.55 |
| | $y\ ^{11}F_2$ | 27660.50 | 200.67 |
| $4f^7\ 5d^2(a\ ^{10}F^\circ)6p$ | $z\ ^{11}G_9$ | 28432.98 | |
| | $z\ ^{11}G_8$ | 27536.47 | 896.51 |
| | $z\ ^{11}G_7$ | 26870.43 | 666.04 |
| | $z\ ^{11}G_6$ | 26337.09 | 533.34 |
| | $z\ ^{11}G_5$ | 25940.15 | 396.94 |
| | $z\ ^{11}G_4$ | 25571.69 | 368.46 |
| | $z\ ^{11}G_3$ | 25403.28 | 168.41 |
| | $z\ ^{11}G_2$ | 25164.67 | 238.61 |
| | $z\ ^{11}G_1$ | 25069.21 | 95.46 |

Miscellaneous even levels.

| Desig. | Level |
|---|---|
| $1_2$ | 16920.37 |
| $2_{2,3}$ | 16923.36 |
| $3_{2,3}$ | 17380.80 |
| $4_3$ | 17617.74 |
| $5_2$ | 17760.90 |
| $6_4$ | 17973.60 |
| $7_4$ | 19164.76 |
| $8_5$ | 19479.99 |
| $9_2$ | 21450.14 |
| $10_3$ | 21857.51 |
| $11_4$ | 22225.57 |
| $12_5$ | 22718.35 |
| $13_{5,6}$ | 24854.33 |
| $14_4$ | 24988.89 |
| $15_3$ | 25253.86 |
| $16_2$ | 25337.78 |
| $17_{1,2}$ | 25352.71 |
| $18_5$ | 25380.91 |
| $19_{5,6}$ | 25815.33 |
| $20_4$ | 25820.75 |
| $21_3$ | 26247.65 |
| $22_5$ | 26335.69 |
| $23_7$ | 26924.55 |
| $24_4$ | 27040.91 |
| $25_5$ | 27081.13 |
| $26_5$ | 27315.82 |
| $27_{5,6}$ | 27336.92 |
| $28_2$ | 27475.78 |
| $29_5$ | 27571.69 |
| $30_4$ | 27705.05 |
| $31_3$ | 27736.70 |
| $32_4$ | 28168.71 |
| $33_5$ | 28415.00 |
| $34_{1,2}$ | 28447.57 |
| $35_5$ | 28474.89 |
| $36_{5,7}$ | 28504.46 |
| $37_6$ | 28731.66 |
| $38_4$ | 28793.42 |
| $39_2$ | 29089.99 |
| $40_5$ | 29120.00 |
| $41_4$ | 29209.25 |
| $42_4$ | 29358.68 |
| $43_3$ | 29426.47 |
| $44_5$ | 29451.41 |
| $45_2$ | 29681.36 |
| $46_2$ | 29717.28 |
| $47_2$ | 29835.15 |
| $48_5$ | 29888.23 |
| $49_5$ | 30197.34 |
| $50_4$ | 30307.53 |
| $51_2$ | 30394.65 |
| $52_3$ | 30809.43 |
| $53_3$ | 31327.60 |
| $54_4$ | 32061.55 |
| $55_5$ | 32221.22 |
| $56_5$ | 32226.74 |
| $57_3$ | 32272.17 |
| $58_2$ | 32384.08 |
| $59_3$ | 32448.16 |
| $60_5$ | 32563.62 |
| $61_4$ | 32886.32 |
| $62_5$ | 33231.12 |
| $63_5$ | 33348.24 |
| $64_4$ | 33568.07 |
| $65_5$ | 33851.88 |
| $66_4$ | 34458.28 |
| $67_3$ | 34465.97 |
| $68_{4,5}$ | 34517.72 |
| $69_2$ | 34765.68 |
| $70_4$ | 34837.02 |
| $71_5$ | 34938.45 |
| $72_{4,5}$ | 34951.05 |
| $73_2$ | 35100.05: |
| $74_{5,6}$ | 35149.14: |
| $75_2$ | 35342.38 |
| $76_5$ | 35794.71 |
| $77_2$ | 36037.32 |
| $78_5$ | 36147.18 |
| $79_4$ | 36191.80 |
| $80_5$ | 36203.27 |
| $81_5$ | 36394.53 |
| $82_{4,5}$ | 36405.29: |
| $83_2$ | 36557.09 |
| $84_{5,6}$ | 37279.44 |
| $85_5$ | 37425.14 |

TABLE IX. Classified lines of Gd I.

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 10629.1 | 6 | | | 9405.6 | 5.36 | $a\ {}^{11}F_6^\circ - z\ {}^{11}D_6$ |
| 10622.2 | 2 | | | 9411.7 | 1.50 | $a\ {}^{11}F_5^\circ - z\ {}^{11}F_5$ |
| 10510.90 | 5 | | | 9511.33 | 0.86 | $a\ {}^{11}F_3^\circ - z\ {}^{11}D_3$ |
| 10505.40 | 20 | | | 9516.31 | 5.96 | $a\ {}^{11}F_8^\circ - z\ {}^{11}D_7$ |
| 10364.56 | 8 | | | 9645.62 | 5.60 | $a\ {}^{11}F_5^\circ - z\ {}^{11}D_4$ |
| 10324.33 | 20 | | | 9683.21 | 3.13 | $a\ {}^{11}F_2^\circ - z\ {}^{11}D_2$ |
| 10321.89 | 5 | | | 9685.50 | 5.47 | $a\ {}^{7}D_4^\circ - 1_2$ |
| 10284.01 | 10 | | | 9721.17 | 1.14 | $a\ {}^{11}F_5^\circ - z\ {}^{11}P_4$ |
| 10219.68 | 80 | | | 9782.36 | 2.30 | $a\ {}^{11}F_6^\circ - z\ {}^{11}D_5$ |
| 10161.31 | 100 | | | 9838.55 | 8.54 | $a\ {}^{11}F_6^\circ - z\ {}^{11}D_6$ |
| 10151.47 | 20 | | | 9848.09 | 8.11 | $a\ {}^{7}D_3^\circ - z\ {}^{11}P_4$ |
| 10034.74 | 40 | | | 9962.65 | 2.65 | $a\ {}^{11}F_7^\circ - z\ {}^{11}F_8$ |
| 9959.00 | 80 | | | 10038.42 | 8.36 | $a\ {}^{11}F_4^\circ - z\ {}^{11}P_4$ |
| 9930.58 | 200 | | | 10067.15 | 7.11 | $a\ {}^{11}F_7^\circ - z\ {}^{11}D_7$ |
| 9898.72 | 150 | | | 10099.55 | 9.52 | $a\ {}^{11}F_4^\circ - z\ {}^{11}D_5$ |
| 9730.52 | 50 | | | 10274.13 | 4.16 | $a\ {}^{11}F_3^\circ - z\ {}^{11}P_4$ |
| 9306.07 | 10 | | | 10742.73 | 2.76 | $a\ {}^{9}F_7^\circ - z\ {}^{9}D_6$ |
| 9081.04 | 2 | 2? | IV? | 11008.94 | 9.01 | $a\ {}^{11}F_4^\circ - z\ {}^{9}F_3$ |
| 9008.0 | 1 | ? | V? | 11098.2 | 8.29 | $a\ {}^{5}F_3^\circ - y\ {}^{9}P_4$ |
| 9006.4 | 1 | — | V | 11100.2 | 0.21 | $10_3 - e\ {}^{9}D_2^\circ$ |
| 8926.46 | 4 | — | V | 11199.58 | 9.56 | $a\ {}^{11}F_3^\circ - z\ {}^{9}F_2$ |
| 8907.57 | 2 | — | V | 11223.33 | 3.33 | $z\ {}^{9}D_4 - e\ {}^{9}D_5^\circ$ |
| 8894.74 | 3 | 5? | IV? | 11239.53 | 9.57 | $a\ {}^{11}F_2^\circ - 4_3$ |
| 8867.31 | 25 | 10 | IV | 11274.28 | 4.28 | $a\ {}^{7}D_4^\circ - z\ {}^{7}P_4$ |
| 8849.14 | 20 | ? | V? | 11297.43 | 7.40 | $a\ {}^{11}F_4^\circ - z\ {}^{9}F_4$ |
| 8839.93 | 2 | — | V | 11309.20 | 9.09 | $11_4 - e\ {}^{9}D_4^\circ$ |
| 8817.60 | 4 | — | V | 11337.84 | 7.74 | $10_2 - e\ {}^{9}D_3^\circ$ |
| 8814.39 | 3 | 2? | IV? | 11341.97 | 2.01 | $a\ {}^{9}F_4^\circ - 11_4$ |
| 8795.76 | 60 | 40 | III | 11366.00 | 5.99 | $a\ {}^{9}F_6^\circ - z\ {}^{9}D_5$ |
| 8791.26 | 8 | — | V | 11371.82 | 1.83 | $a\ {}^{11}F_2^\circ - z\ {}^{9}F_2$ |
| 8784.85 | 80 | 50 | III | 11380.11 | 0.08 | $a\ {}^{11}F_3^\circ - z\ {}^{9}F_4$ |
| 8770.36 | 150 | 40? | IV? | 11398.91 | 8.91 | $a\ {}^{9}F_6^\circ - z\ {}^{9}D_6$ |
| 8764.95 | 2 | — | V | 11405.95 | 5.72 | $a\ {}^{11}F_5^\circ - z\ {}^{7}P_4$? |
| 8756.40 | 6 | — | V | 11417.09 | 7.08 | $a\ {}^{11}F_2^\circ - z\ {}^{9}F_2$ |
| 8752.77 | 30 | — | V | 11421.82 | 1.83 | $a\ {}^{9}F_5^\circ - 12_5$ |
| 8751.70 | 15 | ? | V? | 11423.22 | 3.16 | $a\ {}^{11}F_3^\circ - 6_4$ |
| 8674.86 | 80 | — | V | 11524.40 | 4.39 | $a\ {}^{9}F_5^\circ - z\ {}^{9}D_4$ |
| 8668.63 | 1500*d*? | 1000 | III | 11532.68 | 2.69 | $a\ {}^{7}D_5^\circ - z\ {}^{7}P_4$ |
| 8649.26 | 20? | ? | V? | 11558.51 | 8.52 | $z\ {}^{9}D_5 - e\ {}^{9}D_5^\circ$ |
| 8596.6 | 2 | — | V | 11629.3 | 9.29 | $y\ {}^{9}P_5 - e\ {}^{9}D_4^\circ$ |
| 8594.95 | 50 | 10 | IV | 11631.55 | 1.54 | $a\ {}^{7}D_1^\circ - z\ {}^{7}D_1$ |
| 8561.72 | 300 | 200 | III | 11676.69 | 6.68 | $a\ {}^{7}D_1^\circ - z\ {}^{7}D_2$ |
| 8559.11 | 50 | — | V | 11680.25 | 0.29 | $a\ {}^{9}F_4^\circ - z\ {}^{9}D_3$ |
| 8527.88 | 1000 | 600 | III | 11723.03 | 3.04 | $a\ {}^{7}D_2^\circ - z\ {}^{7}D_1$ |
| 8502.56 | 100*d*? | ? | IV? | 11757.94 | 8.05 | $a\ {}^{9}F_5^\circ - z\ {}^{9}D_2$ |
| 8495.19 | 2 | — | V | 11768.14 | 8.18 | $a\ {}^{7}D_3^\circ - z\ {}^{7}D_2$ |
| 8458.83 | 15? | — | V | 11818.72 | 8.67 | $11_4 - e\ {}^{9}D_5^\circ$ |
| 8447.33 | 20 | — | V | 11834.81 | 4.79 | $a\ {}^{9}F_4^\circ - 12_5$ |
| 8445.47 | 500 | 400 | III | 11837.42 | 7.42 | $a\ {}^{7}D_2^\circ - z\ {}^{7}D_3$ |
| 8429.43 | 8*d*? | ? | V? | 11859.94 | 9.90 | $y\ {}^{9}P_4 - e\ {}^{9}D_4^\circ$ |
| 8401.12 | 60 | — | V | 11899.91 | 9.92 | $a\ {}^{9}F_6^\circ - z\ {}^{9}D_5$ |
| 8398.30 | 800 | 500 | III | 11903.90 | 3.94 | $a\ {}^{7}D_3^\circ - z\ {}^{7}D_2$ |
| 8377.79 | 150 | ? | V? | 11933.05 | 2.84 | $a\ {}^{9}F_6^\circ - z\ {}^{9}D_6$ |
| 8375.98 | 30 | — | V | 11935.63 | 5.63 | $a\ {}^{11}F_5^\circ - z\ {}^{9}F_7$ |
| 8374.76 | 100 | — | V | 11937.36 | 7.35 | $a\ {}^{9}F_4^\circ - z\ {}^{9}D_4$ |
| 8370.16 | 25 | ? | V? | 11943.92 | 3.85 | $a\ {}^{9}F_7^\circ - y\ {}^{9}F_6$ |
| 8349.73 | 500 | 300 | III | 11973.15 | 3.18 | $a\ {}^{7}D_2^\circ - z\ {}^{7}D_2$ |
| 8339.80 | 10 | — | V | 11987.40 | 7.38 | $a\ {}^{9}F_5^\circ - z\ {}^{9}D_5$ |
| 8299.94 | 5 | — | V | 12044.97 | 4.97 | $a\ {}^{11}F_6^\circ - z\ {}^{11}P_5$ |
| 8275.42 | 400 | 300 | III | 12080.66 | 0.63 | $a\ {}^{7}D_2^\circ - z\ {}^{7}D_1$ |
| 8218.08 | 500 | 400 | III | 12164.95 | 4.97 | $a\ {}^{7}D_1^\circ - z\ {}^{7}D_2$ |
| 8214.88 | 10? | ? | V? | 12169.69 | 9.47 | $a\ {}^{9}F_6^\circ - y\ {}^{9}F_5$ |
| 8202.39 | 2 | — | V | 12188.22 | 8.27 | $a\ {}^{7}D_3^\circ - 7_4$ |
| 8191.90 | 2 | — | V | 12203.83 | 3.91 | $a\ {}^{9}F_5^\circ - z\ {}^{9}D_5$ |
| 8185.90 | 20 | 5? | IV? | 12212.78 | 2.79 | $a\ {}^{11}F_7^\circ - z\ {}^{11}P_5$ |
| 8164,80 | 20? | ? | IV? | 12244.34 | 4.44 | $a\ {}^{9}F_5^\circ - z\ {}^{9}D_4$ |
| 8164.26 | 4 | 2 | III | 12245.14 | 5.09 | $a\ {}^{7}D_4^\circ - 8_5$ |
| 8146.15 | 1000 | 1000 | III | 12272.37 | 2.42 | $a\ {}^{7}D_4^\circ - z\ {}^{7}D_4$ |
| 8119.36 | 20 | — | V | 12312.86 | 2.88 | $a\ {}^{9}F_4^\circ - z\ {}^{9}D_5$ |
| 8096.47 | 40 | — | V | 12347.67 | 7.67 | $a\ {}^{9}F_5^\circ - y\ {}^{9}F_4$ |
| 8077.59 | 150 | 100 | IV | 12376.53 | 6.53 | $a\ {}^{11}F_6^\circ - 8_5$ |
| 8076.27 | 4 | 5? | IV? | 12378.55 | 8.52 | $a\ {}^{11}F_4^\circ - 7_4$ |
| 8059.78 | 5 | — | V | 12403.88 | 3.86 | $a\ {}^{11}F_4^\circ - z\ {}^{7}D_4$ |
| 8048.08 | 40 | 30 | IV | 12421.91 | 1.91 | $a\ {}^{11}F_5^\circ - z\ {}^{11}P_5$ |
| 8019.82 | 80 | 40 | IV | 12465.68 | 5.70 | $a\ {}^{7}D_4^\circ - z\ {}^{7}D_5$ |
| 8006.26 | 50 | 30 | IV | 12486.80 | 6.78 | $a\ {}^{11}F_7^\circ - z\ {}^{9}F_7$ |
| 7995.60 | 10? | ? | V? | 12503.44 | 3.50 | $a\ {}^{7}D_5^\circ - 8_5$ |
| 7993.82 | 80 | 10 | IV | 12506.23 | 6.24 | $a\ {}^{9}F_4^\circ - y\ {}^{9}F_3$ |
| 7978.15 | 150 | 60 | III | 12530.79 | 0.83 | $a\ {}^{7}D_5^\circ - z\ {}^{7}D_4$ |
| 7966.66 | 25 | 15 | IV | 12548.86 | 8.88 | $a\ {}^{7}D_5^\circ - z\ {}^{11}P_5$ |
| 7936.11 | 5 | — | V | 12597.17 | 7.14 | $a\ {}^{11}F_5^\circ - z\ {}^{7}D_5$ |
| 7934.33 | 20 | 2? | IV? | 12600.00 | 0.00 | $a\ {}^{9}F_6^\circ - y\ {}^{9}F_5$ |
| 7925.28 | 4 | — | V | 12614.39 | 4.32 | $a\ {}^{11}F_5^\circ - 7_4$ |
| 7910.08 | 200 | —? | V? | 12638.62 | 8.60 | $a\ {}^{9}F_5^\circ - y\ {}^{9}F_2$ |
| 7902.31 | 20 | — | V | 12651.05 | 1.03 | $z\ {}^{11}P_5 - e\ {}^{11}D_6^\circ$ |
| 7884.39 | 20 | 20 | IV | 12679.81 | 9.74 | $a\ {}^{11}F_6^\circ - z\ {}^{11}P_5$ |
| 7869.72 | 200 | 20 | IV | 12703.44 | 3.40 | $a\ {}^{9}F_6^\circ - y\ {}^{9}F_5$ |
| 7856.93 | 1000 | 400 | III | 12724.12 | 4.11 | $a\ {}^{7}D_5^\circ - z\ {}^{7}D_5$ |
| 7847.65 | 4 | 4 | IV | 12739.17 | 9.13 | $a\ {}^{11}F_4^\circ - z\ {}^{11}P_5$ |
| 7845.80 | 20 | — | V E? | 12742.17 | 2.20 | $7_4 - e\ {}^{11}D_5^\circ$ |
| 7844.87 | 300 | 10 | V E IV | 12743.68 | 3.70 | $a\ {}^{9}F_2^\circ - y\ {}^{9}F_1$ |
| 7834.46 | 12 | 10 | IV | 12760.62 | 0.63 | $a\ {}^{9}F_4^\circ - y\ {}^{9}F_4$ |
| 7802.20 | 1 | — | V | 12813.38 | 3.33 | $a\ {}^{9}F_3^\circ - y\ {}^{9}F_3$ |
| 7761.00 | 6 | 10 | IV | 12881.40 | 1.38 | $a\ {}^{9}F_1^\circ - y\ {}^{9}F_1$ |
| 7755.97 | 30 | 20 | IV | 12889.75 | 9.74 | $a\ {}^{9}F_7^\circ - y\ {}^{9}F_7$ |
| 7749.30 | 400 | 800 | I A | 12900.84 | 0.84 | $a\ {}^{9}D_4^\circ - z\ {}^{9}P_3$ |
| 7748.96 | 5? | ? | IV? | 12901.41 | 1.35 | $z\ {}^{11}P_5 - e\ {}^{11}D_6^\circ$ |
| 7733.50 | 1500 | 2000 | I | 12927.20 | 7.17 | $a\ {}^{9}D_5^\circ - z\ {}^{9}P_4$ |
| 7717.66 | 6 | 15 | IV A | 12953.73 | 3.73 | $a\ {}^{11}F_6^\circ - z\ {}^{9}F_7$ |
| 7694.45 | 30 | 30 | IV | 12992.81 | 2.81 | $a\ {}^{9}F_1^\circ - y\ {}^{9}F_2$ |
| 7683.36 | 12*d* | — | V | 13011.56 | 1.64 | $7_4 - e\ {}^{11}D_4^\circ$ |
| 7677.16 | 8 | — | V | 13022.07 | 2.19 | $z\ {}^{11}P_5 - e\ {}^{11}D_5^\circ$ |
| 7676.06 | 15 | 8 | IV | 13023.94 | 3.88 | $a\ {}^{9}F_6^\circ - 13_{5,6}$ |
| 7672.56 | 100 | 80 | IV | 13029.88 | 9.86 | $a\ {}^{9}F_2^\circ - y\ {}^{9}F_2$ |
| 7650.32 | 80 | 60 | IV | 13067.76 | 7.72<br>7.57 | $a\ {}^{9}F_3^\circ - y\ {}^{9}F_4$<br>$(8_5 - e\ {}^{11}D_5^\circ)$ |
| 7621.96 | 40 | 30 | IV | 13116.38 | 6.36 | $a\ {}^{9}F_4^\circ - y\ {}^{9}F_5$ |
| 7611.78 | 15 | 5 | IV | 13133.92 | 3.93 | $a\ {}^{9}F_5^\circ - y\ {}^{9}F_6$ |
| 7588.20 | 15 | 5 | IV | 13174.73 | 4.75 | $a\ {}^{9}F_7^\circ - y\ {}^{9}D_6$ |
| 7566.10 | 8 | 5 | IV | 13213.22 | 3.20 | $a\ {}^{9}F_6^\circ - y\ {}^{9}D_5$ |
| 7562.97 | 150 | 400 | I A | 13218.68 | 8.69 | $a\ {}^{9}D_5^\circ - z\ {}^{9}P_3$ |
| 7464.36 | 200 | 600 | I A | 13393.31 | 3.30 | $a\ {}^{9}D_4^\circ - z\ {}^{9}P_4$ |
| 7441.85 | 200 | 600 | I A | 13433.82 | 3.82 | $a\ {}^{9}D_3^\circ - z\ {}^{9}P_3$ |
| 7430.19 | 15 | 150 | II A | 13454.91 | 4.92 | $a\ {}^{9}D_6^\circ - z\ {}^{11}F_5$ |
| 7385.62 | 2 | — | V | 13536.10 | 6.12 | $z\ {}^{11}P_5 - e\ {}^{11}D_6^\circ$ |
| 7380.28 | 20 | 25 | IV | 13545.90 | 5.89 | $a\ {}^{9}F_6^\circ - y\ {}^{9}F_7$ |
| 7377.77 | 6 | 8 | IV | 13550.50 | 0.46 | $a\ {}^{9}F_6^\circ - 18_5$ |
| 7376.41 | 30 | 40 | IV | 13553.00 | 2.98 | $a\ {}^{9}F_5^\circ - y\ {}^{9}D_4$ |
| 7373.81 | 25 | 25 | IV | 13557.78 | 7.85<br>7.81 | $z\ {}^{7}D_3 - e\ {}^{9}D_2^\circ$<br>$a\ {}^{9}F_5^\circ - 13_{5,6}$ |
| 7360.95 | 2 | — | V | 13581.47 | 1.59 | $8_5 - e\ {}^{11}D_6^\circ$ |
| 7327.07 | 8 | 2? | IV? | 13644.27 | 4.31 | $z\ {}^{11}P_5 - e\ {}^{11}D_7^\circ$ |
| 7319.04 | 4 | — | V | 13659.24 | 9.29 | $a\ {}^{9}F_7^\circ - x\ {}^{9}F_7$ |
| 7313.28 | 50 | 1000 | II A | 13670.00 | 0.03 | $a\ {}^{9}D_5^\circ - z\ {}^{11}F_4$ |
| 7303.74 | 2 | — | V | 13687.85 | 7.93 | $z\ {}^{7}D_4 - e\ {}^{9}D_3^\circ$ |
| 7291.35 | 30 | 600 | II A | 13711.11 | 1.15 | $a\ {}^{9}D_5^\circ - z\ {}^{9}P_4$ |
| 7262.66 | 125 | 1500 | II A | 13765.27 | 5.29 | $a\ {}^{9}D_4^\circ - z\ {}^{11}F_5$ |
| 7246.80 | 1 | — | V | 13795.40 | 5.38 | $z\ {}^{7}D_2 - e\ {}^{9}D_3^\circ$ |
| 7246.39 | 3? | 15 | IV A | 13796.18 | 6.19 | $a\ {}^{7}D_1^\circ - 9_2$ |
| 7233.45 | 100 | 1500 | II A | 13820.86 | 0.87 | $a\ {}^{9}D_5^\circ - z\ {}^{11}F_7$ |
| 7228.02 | 20 | 25 | IV | 13831.24 | 1.28 | $a\ {}^{9}F_4^\circ - y\ {}^{9}D_2$ |
| 7198.63 | 2 | 5? | IV A? | 13887.71 | 7.69 | $a\ {}^{7}D_2^\circ - 9_2$ |
| 7168.37 | 3000 | 2000 | I | 13946.34 | 6.33 | $a\ {}^{9}D_6^\circ - z\ {}^{9}P_5$ |
| 7158.28 | 150 | 50 | III | 13965.99 | 5.94 | $a\ {}^{9}F_4^\circ - y\ {}^{9}D_4$ |
| 7152.95 | 5 | — | V | 13976.40 | 6.44 | $z\ {}^{9}F_4 - e\ {}^{11}D_5^\circ$ |
| 7150.77 | 25 | 30 | IV | 13980.66 | 0.69 | $a\ {}^{7}D_2^\circ - y\ {}^{9}P_2$ |
| 7136.15 | 4 | — | V | 14009.30 | 9.29 | $z\ {}^{11}P_5 - e\ {}^{9}D_4^\circ$ |
| 7127.01 | 3 | — | V | 14027.27 | 7.34 | $z\ {}^{7}D_4 - e\ {}^{9}D_4^\circ$ |
| 7125.38 | 2 | — | V | 14030.48 | 0.49 | $7_4 - e\ {}^{9}D_5^\circ$ |
| 7122.57 | 800 | 3000 | I A | 14036.01 | 6.00 | $a\ {}^{9}D_2^\circ - z\ {}^{11}F_3$ |
| 7100.71 | 40 | 10 | IV | 14079.22 | 9.18 | $a\ {}^{9}F_2^\circ - y\ {}^{9}D_2$ |

TABLE IX.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 7099.44 | 20 | 2? | IV? | 14081.74 | 1.71 | $a\ {}^9F_7^\circ - z\ {}^9F_8$ |
| 7098.73 | 80 | 500 | II A | 14083.15 | 3.14 | $a\ {}^9D_3^\circ - z\ {}^{11}F_3$ |
| 7098.11 | 125 | 20 | IV | 14084.38 | 4.39 | $a\ {}^9F_8^\circ - 18_8$ |
| 7093.90 | 25 | — | V | 14092.74 | 2.76 | $z\ {}^9F_8 - e\ {}^{11}D_4^\circ$ |
| 7087.57 | 2 | — | V | 14105.33 | 5.33 | $a\ {}^9F_4^\circ - 14_4$ |
| 7084.18 | 20 | —? | V? / V E | 14112.08 | 1.71 | $z\ {}^9F_3 - e\ {}^{11}D_2^\circ$ |
| 7082.02 | 3 | — | V | 14116.38 | 6.45 | $a\ {}^7D_3^\circ - y\ {}^9P_3$ |
| 7073.63 | 250 | 1000 | II A | 14133.12 | 3.16 | $a\ {}^9D_{4\frac{1}{2}} - z\ {}^{11}F_4$ |
| 7072.78 | 2 | — | V | 14134.82 | 4.79 | $z\ {}^7D_3 - e\ {}^9D_4^\circ$ |
| 7072.12 | 1 | — | V | 14136.14 | 6.16 | $a\ {}^9D_4^\circ - z\ {}^{11}F_4$ |
| 7071.00 | 250 | 50 | IV | 14138.38 | 8.37 | $a\ {}^9F_3^\circ - y\ {}^9D_3$ |
| 7052.79 | 80 | 300 | II A | 14174.88 | 4.87 | $a\ {}^9D_4^\circ - z\ {}^{11}F_5$ |
| 7016.60 | 80 | 60 | III | 14248.00 | 8.07 | $a\ {}^7D_3^\circ - y\ {}^9P_4$ |
| 7004.30 | 4 | 2? | IV? | 14273.02 | 3.03 | $a\ {}^9F_3^\circ - y\ {}^9D_4$ |
| 7003.24 | 4 | — | V | 14275.18 | 5.17 | $a\ {}^9F_4^\circ - z\ {}^{11}G_4$ |
| 6993.18 | 200 | 40 | IV | 14295.71 | 5.71 | $a\ {}^9F_3^\circ - y\ {}^9D_2$ |
| 6991.92 | 1500 | 3000 | I A | 14298.29 | 8.27 | $a\ {}^9D_3^\circ - z\ {}^{11}F_3$ |
| 6983.53 | 20 | 2? | IV? | 14315.47 | 5.44 | $a\ {}^9F_6^\circ - x\ {}^9F_7$ |
| 6980.86 | 250 | — | V E / V | 14320.94 | 0.83 | $z\ {}^9F_7 - e\ {}^9D_5^\circ$ |
| 6969.81 | 5 | — | V | 14343.64 | 3.64 | $z\ {}^7D_5 - e\ {}^9D_5^\circ$ |
| 6964.33 | 50 | 20 | IV | 14354.93 | 4.90 | $a\ {}^9F_3^\circ - y\ {}^9D_2$ |
| 6956.88 | 5 | — | V | 14370.30 | 0.30 | $a\ {}^9F_4^\circ - 15_2$ |
| 6950.35 | 5 | — | V | 14383.80 | 3.83 | $a\ {}^9F_7^\circ - z\ {}^{11}G_7$ |
| 6936.5 | 1 | — | V | 14412.52 | 2.42 | $a\ {}^9F_3^\circ - 14_4$ |
| 6926.49 | 150 | 50 | III | 14433.35 | 3.39 | $a\ {}^9F_1^\circ - y\ {}^9D_2$ |
| 6924.28 | 3 | — | V | 14437.96 | 7.95 | $a\ {}^9F_7^\circ - 23_7$ |
| 6916.57 | 2000 | 4000 | I A | 14454.05 | 4.01 | $a\ {}^9D_3^\circ - z\ {}^{11}F_4$ |
| 6905.50 | 40 | — | V | 14477.22 | 7.30 | $z\ {}^9F_8 - e\ {}^{11}D_5^\circ$ |
| 6895.90 | 15 | 10 | IV | 14497.38 | 7.35 | $a\ {}^9F_4^\circ - 18_8$ |
| 6892.14 | 10 | — | V | 14505.29 | 5.24 | $a\ {}^9F_6^\circ - 22_9$ |
| 6891.41 | 4 | 4? | IV? | 14506.82 | 6.64 | $a\ {}^9F_6^\circ - z\ {}^{11}G_6$ |
| 6877.0 | 2 | — | V | 14537.2 | 6.92 | $z\ {}^7D_4 - e\ {}^9D_5^\circ$ |
| 6852.94 | 4 | — | V | 14588.26 | 8.20 | $a\ {}^9F_3^\circ - z\ {}^{11}G_3$ |
| 6849.89 | 30 | — | V | 14594.76 | 4.82 | $z\ {}^{11}P_6 - e\ {}^9D_6^\circ$ |
| 6828.25 | 1500 | 5000 | I A | 14641.00 | 1.00 | $a\ {}^9D_4^\circ - z\ {}^{11}F_5$ |
| 6827.03 | 6 | 2? | IV? | 14643.62 | 3.63 | $a\ {}^9F_6^\circ - z\ {}^{11}G_6$ |
| 6816.49 | 150 | 500 | II A | 14666.27 | 6.28 | $a\ {}^9D_3^\circ - z\ {}^9P_3$ |
| 6814.56 | 50 | 50 | III | 14670.42 | 0.47 | $a\ {}^7D_4^\circ - y\ {}^9P_3$ |
| 6783.39 | 50 | 25 | IV | 14737.83 | 7.86 | $a\ {}^9F_6^\circ - x\ {}^9F_8$ |
| 6755.43 | 1 | — | V | 14798.83 | 8.88 | $a\ {}^7D_3^\circ - 11_4$ |
| 6730.73 | 1500 | 5000 | I A | 14853.14 | 3.11 | $a\ {}^9D_4^\circ - z\ {}^{11}F_4$ |
| 6692.86 | 20 | 60 | IV A | 14937.18 | 7.19 | $a\ {}^9F_4^\circ - 20_4$ |
| 6674.70 | 1 | — | V | 14977.82 | 7.85 / 7.84 | $z\ {}^9F_8 - e\ {}^{11}D_6^\circ$ / $a\ {}^9F_3^\circ - 16_2$ |
| 6668.74 | 1 | —? | V | 14991.20 | 1.23 | $z\ {}^9F_8 - e\ {}^{11}D_6^\circ$ |
| 6667.00 | 4 | — | V | 14995.12 | 5.22 | $a\ {}^9F_4^\circ - z\ {}^{11}G_4$ |
| 6653.55 | 10 | 10 | IV | 15025.43 | 5.48 | $z\ {}^7P_4 - e\ {}^9D_4^\circ$ |
| 6647.11 | 10 | 20 | IV A | 15039.99 | 9.98 | $a\ {}^9F_6^\circ - z\ {}^{11}G_7$ |
| 6646.85 | 10 | 30 | IV A | 15040.57 | 0.57 | $a\ {}^9F_4^\circ - z\ {}^{11}G_5$ |
| 6643.98 | 150 | 30 | IV | 15047.07 | 7.03 | $z\ {}^{11}D_7 - e\ {}^{11}D_6^\circ$ |
| 6642.76 | 10 | 30 | IV A | 15049.84 | 9.87 | $a\ {}^9F_7^\circ - z\ {}^{11}G_8$ |
| 6640.76 | 3 | — | V | 15054.37 | 4.36 | $z\ {}^7D_5 - e\ {}^9D_6^\circ$ |
| 6640.08 | 300 | 4000 | II A | 15055.91 | 5.91 | $a\ {}^9D_5^\circ - z\ {}^{11}F_7$ |
| 6639.73 | 3 | — | V | 15056.70 | 6.59 | $a\ {}^9F_4^\circ - z\ {}^{11}G_5$ |
| 6633.32 | 3 | 20? | IV A | 15071.25 | 1.27 | $a\ {}^{11}F_4^\circ - 10_3$ |
| 6628.43 | 40 | 10 | IV | 15082.37 | 2.36 | $z\ {}^{11}P_4 - e\ {}^{11}D_5^\circ$ |
| 6610.97 | 2 | 2 | IV | 15122.20 | 2.11 | $a\ {}^{11}F_5^\circ - 11_4$ |
| 6604.54 | 6 | 10 | IV | 15136.93 | 7.16 | $a\ {}^7D_3^\circ - z\ {}^9D_3$ |
| 6593.42 | 100 | 10? | IV? | 15162.46 | 2.47 | $z\ {}^9F_8 - e\ {}^9D_5^\circ$ |
| 6591.60 | 200 | 3000 | II A | 15166.64 | 6.70 | $a\ {}^9D_5^\circ - z\ {}^{11}D_5$ |
| 6578.49 | 5 | 400 | II A | 15196.87 | 6.93 | $a\ {}^9D_4^\circ - z\ {}^{11}D_4$ |
| 6573.80 | 40 | 10 | IV | 15207.71 | 7.72 | $z\ {}^9F_8 - e\ {}^9D_5^\circ$ |
| 6564.78 | 500 | 40 | IV | 15228.60 | 8.62 | $z\ {}^{11}D_8 - e\ {}^{11}D_6^\circ$ |
| 6560.74 | 4? | 20 | IV A | 15237.98 | 7.95 | $a\ {}^{11}F_6^\circ - 12_5$ |
| 6555.97 | 5 | 30 | IV A | 15249.07 | 9.08 | $a\ {}^7D_3^\circ - 11_4$ |
| 6549.25 | 100 | 20 | IV | 15264.72 | 4.73 | $z\ {}^9F_4 - e\ {}^9D_5^\circ$ |
| 6544.86 | 5? | 2? | IV? | 15274.96 | 4.97 | $8_8 - e\ {}^9D_6^\circ$ |
| 6538.15 | 300 | 40 | IV | 15290.63 | 0.64 | $z\ {}^{11}D_8 - e\ {}^{11}D_6^\circ$ |
| 6526.25 | 15 | 20 | IV | 15318.51 | 8.55 | $a\ {}^9F_6^\circ - x\ {}^9F_8$ |
| 6521.80 | 6 | — | V | 15328.96 | 8.95 | $a\ {}^7D_4^\circ - z\ {}^9D_2$ |
| 6512.08 | 1? | 8 | IV A | 15351.84 | 1.80 | $z\ {}^{11}P_4 - e\ {}^{11}D_4^\circ$ |
| 6472.70 | 25d | 4 | IV | 15445.24 | 5.25 | $z\ {}^9F_2 - e\ {}^9D_2^\circ$ |
| 6471.66 | 2 | — | V | 15447.72 | 7.72 | $z\ {}^9F_1 - e\ {}^9D_2^\circ$ |
| 6470.29 | 30 | 4 | IV | 15451.00 | 1.02 | $z\ {}^9F_3 - e\ {}^9D_4^\circ$ |
| 6469.80 | 2 | 4 | IV A | 15452.17 | 2.13 | $a\ {}^9F_4^\circ - 22_5$ |
| 6456.74 | 15 | 40 | III A | 15483.42 | 3.45 | $a\ {}^7D_4^\circ - 12_5$ |
| 6438.07 | 2 | 50 | III A | 15528.32 | 8.32 | $a\ {}^9D_4^\circ - z\ {}^{11}D_3$ |
| 6435.27 | 15 | — | V | 15535.08 | 5.06 | $z\ {}^7P_4 - e\ {}^9D_5^\circ$ |
| 6432.74 | 2 | 10 | IV A | 15541.19 | 1.19 | $a\ {}^7D_2^\circ - y\ {}^9F_1$ |
| 6424.52 | 20 | 30 | III | 15561.07 | 1.12 / 1.06 | $a\ {}^7D_1^\circ - y\ {}^9F_2$ / $6_4 - e\ {}^9D_4^\circ$ |
| 6418.00 | 2 | 1? | IV? | 15576.88 | 6.92 | $3_{2,3} - e\ {}^9D_2^\circ$ |
| 6417.77 | 5 | 3 | IV | 15577.44 | 7.51 | $4_3 - e\ {}^9D_3^\circ$ |
| 6414.26 | 2 | 5 | IV A | 15585.96 | 6.01 | $a\ {}^7D_4^\circ - z\ {}^9D_4$ |
| 6408.55 | 60 | 2000 | II A | 15599.85 | 9.88 | $a\ {}^9D_4^\circ - z\ {}^{11}D_5$ |
| 6402.38 | 3 | 20 | IV A | 15614.88 | 4.89 | $a\ {}^{11}F_5^\circ - 12_5$ |
| 6382.69 | 4 | 60 | III A | 15663.05 | 3.06 | $a\ {}^9D_4^\circ - z\ {}^{11}D_4$ |
| 6379.37 | 4 | 5 | IV | 15671.21 | 1.18 | $a\ {}^9F_5^\circ - 21_5$ |
| 6363.23 | 20 | 10 | IV | 15710.95 | 0.92 | $z\ {}^{11}D_4 - e\ {}^{11}D_5^\circ$ |
| 6361.15 | 3 | 15 | IV A | 15716.09 | 6.04 | $a\ {}^{11}F_6^\circ - z\ {}^9D_5$ |
| 6360.59 | 12 | 150 | III | 15717.47 | 7.45 | $a\ {}^{11}F_6^\circ - z\ {}^9D_4$ |
| 6358.37 | 3 | — | V E? | 15722.96 | 2.96 | $z\ {}^{11}P_4 - e\ {}^{11}D_5^\circ$ |
| 6353.83 | 4 | 4? | IV | 15734.20 | 4.19 | $z\ {}^9F_8 - e\ {}^{11}D_7^\circ$ |
| 6351.72 | 12 | 8 | IV | 15739.41 | 9.41 | $z\ {}^9F_3 - e\ {}^9D_4^\circ$ |
| 6350.46 | 10 | 6 | IV | 15742.55 | 2.55 | $z\ {}^{11}D_8 - e\ {}^{11}D_6^\circ$ |
| 6349.72 | 4 | 5 | IV | 15744.38 | 4.39 | $a\ {}^9F_6^\circ - 24_4$ |
| 6347.87 | 8 | 50 | III A | 15748.97 | 8.96 | $a\ {}^{11}F_6^\circ - z\ {}^9D_5$ |
| 6336.34 | 25 | 200 | III A | 15777.63 | 7.61 | $a\ {}^{11}F_4^\circ - z\ {}^9D_2$ |
| 6333.75 | 15 | 150 | III A | 15784.08 | 4.08 | $a\ {}^{11}F_2^\circ - z\ {}^9D_2$ |
| 6332.01 | 6 | 10 | IV | 15788.42 | 8.38 | $a\ {}^7D_5^\circ - y\ {}^9F_2$ |
| 6331.35 | 150 | 25 | IV | 15790.06 | 9.99 | $z\ {}^{11}D_7 - e\ {}^{11}D_7^\circ$ |
| 6321.59 | 5 | 2 | IV | 15814.44 | 4.45 | $3_{2,3} - e\ {}^9D_3^\circ$ |
| 6317.19 | 80 | 1500 | II A | 15825.46 | 5.49 | $a\ {}^9D_4^\circ - z\ {}^{11}P_4$ |
| 6316.44 | 10 | 100 | III A | 15827.34 | 7.35 | $a\ {}^7D_3^\circ - y\ {}^9F_2$ |
| 6309.63 | ? | 6 | IV | 15844.42 | 4.42 | $a\ {}^7D_4^\circ - z\ {}^9D_4$ |
| 6309.11 | 40 | — | V E | 15845.72 | 5.66 | $(z\ {}^{11}D_2 - e\ {}^{11}D_2^\circ)$ |
| 6308.95 | 5? | 800 | II A | 15846.12 | 6.17 | $a\ {}^9D_5^\circ - z\ {}^{11}D_3$ |
| 6292.87 | 50 | 1500 | I A | 15886.62 | 6.65 | $a\ {}^9D_4^\circ - z\ {}^{11}D_3$ |
| 6289.68 | ? | 50 | III A | 15894.68 | 4.45 | $z\ {}^{11}F_8 - e\ {}^{11}D_7^\circ$ |
| 6280.88 | 15 | — | V | 15916.94 | 6.92 | $4_3 - e\ {}^9D_4^\circ$ |
| 6265.34 | 20 | 125 | III A | 15956.42 | 6.35 | $a\ {}^{11}F_7^\circ - z\ {}^9D_2$ |
| 6263.62 | 10? | 2 | IV | 15960.80 | 0.60 | $z\ {}^9F_8 - e\ {}^9D_5^\circ$ |
| 6258.45 | 30? | 2? | IV? | 15973.99 | 3.98 | $z\ {}^9F_8 - e\ {}^9D_6^\circ$ |
| 6256.00 | 8? | —? | V? | 15980.24 | 0.36 | $z\ {}^{11}D_4 - e\ {}^{11}D_4^\circ$ |
| 6255.72 | 25 | 1000 | II A | 15980.96 | 0.91 | $a\ {}^9D_5^\circ - z\ {}^{11}D_4$ |
| 6254.99 | 5? | 20 | IV A | 15982.82 | 2.85 | $a\ {}^9F_7^\circ - x\ {}^9F_8$ |
| 6234.73 | ? | 15 | IV A | 16034.76 | 4.67 | $a\ {}^{11}F_4^\circ - z\ {}^9D_4$ |
| 6224.41 | 40? | 2000 | II A | 16061.34 | 1.30 | $a\ {}^9D_5^\circ - z\ {}^{11}D_3$ |
| 6212.15 | 4? | 80 | III A | 16093.04 | 2.98 | $a\ {}^{11}F_5^\circ - z\ {}^9D_5$ |
| 6203.61 | 20 | 25 | IV | 16115.20 | 5.10 | $z\ {}^{11}D_8 - e\ {}^{11}D_6^\circ$ |
| 6199.46 | 5 | 10 | IV A | 16125.98 | 5.90 | $a\ {}^{11}F_6^\circ - z\ {}^9D_5$ |
| 6187.2 | 4 | —? | V? | 16157.9 | 8.23 | $a\ {}^9F_6^\circ - x\ {}^9F_7$ |
| 6180.42 | 300 | 15 | V E / IV | 16175.66 | 5.73 | $z\ {}^{11}D_8 - e\ {}^{11}D_6^\circ$ |
| 6176.58 | 10? | 40 | III A | 16185.72 | 5.68 | $a\ {}^{11}F_7^\circ - z\ {}^9D_2$ |
| 6164.47 | 40 | 80 | III A | 16217.52 | 7.50 | $a\ {}^7D_5^\circ - y\ {}^9F_4$ |
| 6163.53 | 5 | 10 | IV A | 16219.99 | 9.95 | $a\ {}^7D_5^\circ - z\ {}^9D_5$ |
| 6151.06 | 15? | 150 | III A | 16252.87 | 2.87 | $a\ {}^7D_5^\circ - z\ {}^9D_6$ |
| 6144.39 | 5 | 10 | III A | 16270.51 | 0.47 | $a\ {}^{11}F_6^\circ - z\ {}^9D_4$ |
| 6138.34 | 40 | 40 | IV | 16286.55 | 6.52 | $z\ {}^{11}F_7 - e\ {}^{11}D_6^\circ$ |
| 6136.41 | 25? | 800 | II A | 16291.67 | 1.62 | $a\ {}^9D_4^\circ - z\ {}^{11}P_4$ |
| 6135.02 | 15 | 600 | II A | 16295.36 | 5.40 | $a\ {}^9D_4^\circ - z\ {}^{11}D_7$ |
| 6125.81 | 5? | 30 | III A | 16319.86 | 9.83 | $a\ {}^9D_5^\circ - z\ {}^{11}D_5$ |
| 6114.07 | 2000 | 3000 | I | 16351.20 | 1.20 / 1.52 | $a\ {}^9D_6^\circ - z\ {}^9F_6$ / $(z\ {}^{11}D_4 - e\ {}^{11}D_5^\circ)$ |
| 6113.48 | 2? | 60 | III A | 16352.78 | 2.78 | $a\ {}^9D_4^\circ - z\ {}^{11}D_5$ |
| 6109.07 | 80 | 1500 | I A | 16364.58 | 4.58 | $a\ {}^9D_5^\circ - z\ {}^9F_5$ |
| 6072.01 | 5? | 10 | IV | 16464.46 | 4.44 | $a\ {}^9F_5^\circ - 24_4$ |
| 6065.14 | 4 | 2 | IV | 16483.11 | 3.10 | $a\ {}^{11}F_7^\circ - y\ {}^9F_4$ |
| 6064.24 | 8 | 10 | IV | 16485.56 | 5.51 | $z\ {}^{11}D_8 - e\ {}^{11}D_7^\circ$ |

TABLE IX.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 6044.01 | 20 | 50 | III A | 16540.74 | 0.73 | $a\ {}^{11}F_6^\circ - y\ {}^9F_4$ |
| 6021.13 | 50 | 500 | II A | 16603.59 | 3.56 | $a\ {}^{11}F_4^\circ - y\ {}^9F_3$ |
| 6019.01 | 20 | 200 | II A | 16609.44 | 9.47 | $a\ {}^9D_3^\circ - z\ {}^{11}P_4$ |
| 6006.36 | 15 | — | V | 16644.42 | 4.44 | $a\ {}^9F_6^\circ - 35_5$ |
| 5999.08 | 100 | 800 | III A | 16664.62 | 4.63 | $a\ {}^{11}F_5^\circ - y\ {}^9F_2$ |
| 5997.99 | 6 | 20 | IV A | 16667.64 | 7.70 | $a\ {}^7D_4^\circ - y\ {}^9F_4$ |
| 5996.66 | 6 | — | IV | 16671.34 | 1.32 | $z\ {}^9F_5 - e\ {}^9D_5^\circ$ |
| 5995.74 | 5 | 2 | IV | 16673.90 | 4.01 | $a\ {}^9F_6^\circ - 36_{6,7}$ |
| 5992.91 | ? | 3 | IV | 16681.77 | 1.85 | $a\ {}^9F_2^\circ - x\ {}^9F_3$? |
| 5991.84 | 10? | 6 | IV | 16684.75 | 4.70 | $z\ {}^9F_6 - e\ {}^9D_5^\circ$ |
| 5988.02 | 50 | 25 | IV | 16695.40 | 5.34 | $z\ {}^{11}F_6 - e\ {}^{11}D_5^\circ$ |
| 5984.49 | 8 | 800 | II A | 16705.24 | 5.24 | $a\ {}^9D_3^\circ - 1_3$ |
| 5983.41 | 15 | 1000 | II A | 16708.26 | 8.23 | $a\ {}^9D_2^\circ - 2_{2,3}$ |
| 5977.25 | 150 | 1200 | II A | 16725.48 | 5.47 | $a\ {}^{11}F_3^\circ - y\ {}^9F_4$ |
| 5963.17 | 30 | 150 | III A | 16764.97 | 5.02 | $a\ {}^7D_4^\circ - y\ {}^9F_5$ |
| 5937.71 | 150 | 400 | II A | 16836.86 | 6.90 | $a\ {}^{11}F_2^\circ - y\ {}^9F_2$ |
| 5936.84 | 200 | 500 | II A | 16839.32 | 9.36 | $a\ {}^{11}F_3^\circ - y\ {}^9F_3$ |
| 5931.99 | 2 | — | V | 16853.09 | 3.14 | $a\ {}^9F_4^\circ - 31_3$ |
| 5930.29 | 200 | 1200 | II A | 16857.92 | 7.95 | $a\ {}^{11}F_4^\circ - y\ {}^9F_4$ |
| 5923.28 | ? | 10 | IV A | 16877.87 | 7.84 | $a\ {}^{11}F_6^\circ - y\ {}^9F_7$ |
| 5916.77 | 50 | 800 | II A | 16896.44 | 6.46 | $a\ {}^{11}F_5^\circ - y\ {}^9F_5$ |
| 5908.41 | 6 | 600 | II A | 16920.35 | 0.37 | $a\ {}^9D_2^\circ - 1_3$ |
| 5907.37 | 4 | 300 | II A | 16923.33 | 3.36 | $a\ {}^9D_2^\circ - 2_{2,3}$ |
| 5904.56 | 800 | 5000 | I A | 16931.38 | 1.41 | $a\ {}^9D_4^\circ - z\ {}^9F_4$ |
| 5898.06 | 20 | 100 | III A | 16950.04 | 0.05 | $a\ {}^{11}F_6^\circ - y\ {}^9F_6$ |
| 5889.58 | ? | 30 | IV A | 16974.44 | 4.49 | $a\ {}^9D_5^\circ - 6_4$ |
| 5879.89 | 10*d*? | 5 | IV | 17002.42 | 2.42 | $z\ {}^{11}F_5 - e\ {}^{11}D_4^\circ$ |
| 5876.73 | 15 | 100 | III A | 17011.56 | 1.63 | $a\ {}^{11}F_2^\circ - y\ {}^9F_3$ |
| 5872.65 | 2 | 60 | III A | 17023.38 | 3.43 | $a\ {}^7D_5^\circ - y\ {}^9F_5$ |
| 5870.58 | 50 | 25 | IV | 17029.38 | 9.48 | $z\ {}^{11}F_7 - e\ {}^{11}D_7^\circ$ |
| 5856.22 | 4000 | 5000 | I | 17071.14 | 1.15 | $a\ {}^9D_5^\circ - z\ {}^9F_6$ |
| 5851.63 | 5000 | 8000 | I | 17084.53 | 4.53 | $a\ {}^9D_5^\circ - z\ {}^9F_5$ |
| 5848.48 | 30 | 200 | III A | 17093.73 | 3.75 | $a\ {}^{11}F_5^\circ - y\ {}^9F_4$ |
| 5840.94 | 6 | 8 | IV | 17115.80 | 5.84 | $a\ {}^9F_5^\circ - 28_5$ |
| 5827.75 | 5? | 5 | IV | 17154.53 | 4.51 | $a\ {}^9F_5^\circ - y\ {}^{11}F_5$ |
| 5823.97 | 200 | 1500 | II A | 17165.67 | 5.67 | $a\ {}^9D_5^\circ - 3_{2,3}$ |
| 5809.22 | 300 | 30 | IV | 17209.25 | 9.27 | $z\ {}^{11}F_6 - e\ {}^{11}D_6^\circ$ |
| 5807.72 | 40? | 200 | III A | 17213.70 | 3.68 | $a\ {}^{11}F_4^\circ - y\ {}^9F_5$ |
| 5802.92 | 400 | 3000 | II A | 17227.94 | 7.92 | $a\ {}^9D_4^\circ - 5_2$ |
| 5799.65 | 20 | 1 | IV | 17237.65 | 7.82 | $z\ {}^{11}F_4 - e\ {}^{11}D_5^\circ$? |
| 5791.38 | 4000 | 5000 | I | 17262.27 | 2.27 | $a\ {}^9D_4^\circ - z\ {}^9F_3$ |
| 5778.53 | 8 | 6 | IV | 17300.65 | 0.56 | $a\ {}^9F_5^\circ - y\ {}^{11}F_2$ |
| 5776.02 | 200 | 150 | III | 17308.17 | 8.22 | $a\ {}^9F_7^\circ - y\ {}^{11}F_3$ |
| 5769.76 | 100 | 200 | III A | 17326.95 | 6.99 | $a\ {}^{11}F_5^\circ - y\ {}^9F_6$ |
| 5754.17 | 250 | 150 | V E<br>III | 17373.89 | 3.58<br>3.93 | $z\ {}^{11}F_5 - e\ {}^{11}D_5^\circ$<br>$a\ {}^{11}F_6^\circ - 13_{5,6}$ |
| 5753.24 | 8 | 5 | IV | 17376.70 | 6.76 | $a\ {}^9F_2^\circ - 31_3$ |
| 5751.88 | 300 | 2000 | II A | 17380.81 | 0.80 | $a\ {}^9D_2^\circ - 3_{2,3}$ |
| 5746.83 | 30 | — | V | 17396.08 | 6.10 | $z\ {}^9P_5 - e\ {}^{11}D_6^\circ$ |
| 5746.36 | 1000 | 3000 | I A | 17397.51 | 7.54 | $a\ {}^9D_4^\circ - z\ {}^9F_4$ |
| 5744.66 | 400 | 2000 | II A | 17402.66 | 2.61 | $a\ {}^9D_3^\circ - 4_2$ |
| 5735.98 | 150 | 200 | III | 17428.99 | 8.99 | $a\ {}^{11}F_7^\circ - y\ {}^9F_7$ |
| 5732.16 | 100 | 1000 | II A | 17440.60 | 0.62 | $a\ {}^9D_4^\circ - 6_4$ |
| 5727.76 | 20 | 30? | IV | 17454.00 | 3.96 | $a\ {}^7D_4^\circ - y\ {}^9F_4$ |
| 5724.75 | 300 | 150 | III | 17463.18 | 3.23 | $a\ {}^9F_6^\circ - y\ {}^{11}F_7$ |
| 5710.32 | 200 | 30 | IV | 17507.31 | 7.26 | $z\ {}^{11}F_4 - e\ {}^{11}D_4^\circ$ |
| 5709.42 | 500 | 3000 | II A | 17510.07 | 0.00<br>0.07 | $a\ {}^9D_2^\circ - z\ {}^9F_1$<br>$a\ {}^9D_3^\circ - z\ {}^7P_4$? |
| 5705.94 | 10? | 5 | IV | 17520.75 | 0.75 | $a\ {}^9F_7^\circ - z\ {}^9G_6$ |
| 5701.35 | 2500 | 3000 | I | 17534.85 | 4.87 | $a\ {}^9D_2^\circ - z\ {}^9F_2$ |
| 5697.99 | 60 | 30 | IV | 17545.19 | 5.21 | $a\ {}^9F_6^\circ - y\ {}^{11}F_6$ |
| 5696.22 | 8000 | 8000 | I | 17550.64 | 0.66 | $a\ {}^9D_4^\circ - z\ {}^9F_5$ |
| 5692.49 | 5 | 10 | IV A | 17562.14 | 2.20 | $a\ {}^7D_3^\circ - 14_4$ |
| 5692.13 | 200 | 150 | III | 17563.25 | 3.25 | $a\ {}^{11}F_6^\circ - y\ {}^9D_5$ |
| 5690.80 | 15 | 8 | IV | 17567.36 | 7.47 | $a\ {}^9F_4^\circ - y\ {}^{11}F_5$ |
| 5686.66 | 100 | 500 | III A | 17580.15 | 0.12 | $a\ {}^9D_3^\circ - z\ {}^9F_3$ |
| 5677.45 | 200 | 30 | IV | 17608.67 | 8.69 | $z\ {}^{11}F_3 - e\ {}^{11}D_3^\circ$ |
| 5675.55 | 20 | 30 | IV | 17614.56 | 4.60 | $a\ {}^7D_4^\circ - y\ {}^9D_4$ |
| 5674.53 | 8 | 150 | III A | 17617.73 | 7.74 | $a\ {}^9D_2^\circ - 4_2$ |
| 5664.99 | 6? | 3 | IV | 17647.40 | 7.39 | $a\ {}^{11}F_6^\circ - z\ {}^9F_7$ |
| 5653.33 | 80 | 80 | IV | 17683.80 | 3.83 | $a\ {}^7D_1^\circ - 16_2$ |

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 5650.90 | 10 | 20 | IV A | 17691.40 | 1.41 | $a\ {}^7D_2^\circ - 15_2$ |
| 5648.55 | 8 | 15 | IV A | 17698.76 | 8.76 | $a\ {}^7D_1^\circ - 17_{1,2}$ |
| 5643.67 | 100 | 80 | IV | 17714.06 | 4.00 | $a\ {}^{11}F_7^\circ - y\ {}^9D_5$ |
| 5643.24 | 6000 | 6000 | I | 17715.41 | 5.39 | $a\ {}^9D_3^\circ - z\ {}^9F_4$ |
| 5636.07 | 1 | — | V | 17737.95 | 7.98 | $a\ {}^7D_3^\circ - z\ {}^{11}G_2$ |
| 5633.49 | 200 | 300 | III | 17746.07 | 6.04 | $a\ {}^{11}F_5^\circ - y\ {}^9D_4$ |
| 5632.25 | 2500 | 3000 | I | 17749.98 | 0.00 | $a\ {}^9D_2^\circ - z\ {}^9F_2$ |
| 5631.98 | 300 | 100 | IV | 17750.83 | 0.87 | $a\ {}^{11}F_6^\circ - 13_{5,6}$ |
| 5630.99 | 2 | — | V | 17753.95 | 3.99 | $a\ {}^7D_4^\circ - 14_4$ |
| 5629.55 | 800 | 2500 | I A | 17758.49 | 8.47 | $a\ {}^9D_2^\circ - 6_4$ |
| 5628.79 | 10 | 100 | III A | 17760.89 | 0.90<br>0.93 | $a\ {}^9D_2^\circ - 5_2$<br>$a\ {}^9D_3^\circ - 8_3$ |
| 5619.50 | 40 | 30 | IV | 17790.25 | 0.26 | $a\ {}^7D_2^\circ - 17_{1,2}$ |
| 5617.91 | 4000 | 5000 | I | 17795.28 | 5.25 | $a\ {}^9D_2^\circ - z\ {}^9F_2$ |
| 5617.08 | 3 | — | V | 17797.92 | 7.96 | $a\ {}^9F_6^\circ - z\ {}^9G_5$ |
| 5616.87 | 8 | — | V | 17798.58 | 8.70 | $1_3 - e\ {}^9S_4^\circ$ |
| 5614.45 | 125 | 1500 | III A | 17806.25 | 6.31 | $a\ {}^9D_4^\circ - z\ {}^{11}P_4$ |
| 5613.67 | 2 | — | V | 17808.73 | 8.75 | $a\ {}^7D_4^\circ - y\ {}^9D_5$ |
| 5605.93 | 30 | 20? | IV? | 17833.31 | 3.31 | $z\ {}^{11}D_5 - e\ {}^9S_4^\circ$ |
| 5603.58 | 10 | 20? | IV? | 17840.79 | 0.83 | $a\ {}^7D_2^\circ - z\ {}^{11}G_3$ |
| 5594.67 | 8 | — | V | 17869.21 | 9.20<br>9.27 | $z\ {}^{11}D_5 - e\ {}^9D_5^\circ$<br>$z\ {}^9P_5 - e\ {}^9D_4^\circ$ |
| 5594.13 | 500 | 50 | IV | 17870.93 | 0.96 | $z\ {}^{11}F_2 - e\ {}^{11}D_3^\circ$ |
| 5593.49 | 25 | 80 | III A | 17872.98 | 3.01 | $a\ {}^7D_5^\circ - y\ {}^9D_4$ |
| 5591.85 | 1000*d* | 200 | IV | 17878.22 | 8.13<br>8.42 | $z\ {}^{11}F_3 - e\ {}^{11}D_4^\circ$<br>$z\ {}^{11}F_4 - e\ {}^{11}D_4^\circ$ |
| 5589.59 | 20 | 30 | IV | 17885.45 | 5.43 | $a\ {}^{11}F_5^\circ - 14_4$ |
| 5588.95 | 100*d*? | 8? | IV? | 17887.49 | 7.51 | $x\ {}^7F_5 - e\ {}^{11}D_6^\circ$ |
| 5586.76 | 50 | — | V | 17894.51 | 4.47 | $z\ {}^{11}P_4 - e\ {}^9S_4^\circ$ |
| 5586.32 | 150 | 250 | III | 17895.92 | 5.94 | $a\ {}^{11}F_6^\circ - y\ {}^9F_7$ |
| 5584.89 | 10 | 15 | IV | 17900.50 | 0.51 | $a\ {}^{11}F_6^\circ - 18_5$ |
| 5581.96 | 15 | 6 | IV | 17909.89 | 9.86 | $a\ {}^9F_4^\circ - 38_4$ |
| 5581.61 | 80 | 100 | IV | 17911.02 | 1.09 | $a\ {}^7D_5^\circ - 16_2$ |
| 5581.09 | 8 | 2 | IV | 17912.68 | 2.73 | $a\ {}^9F_5^\circ - 41_4$ |
| 5576.13 | 200 | 500 | III A | 17928.52 | 8.60 | $a\ {}^{11}F_4^\circ - y\ {}^9D_3$ |
| 5572.53 | 200 | 500 | III A | 17940.20 | 0.19 | $a\ {}^{11}F_5^\circ - y\ {}^9D_5$ |
| 5568.80 | 10*d*? | — | V | 17952.22 | 2.23 | $z\ {}^{11}F_6 - e\ {}^{11}D_7^\circ$ |
| 5561.37 | ? | 25 | IV A | 17976.20 | 6.20 | $a\ {}^9D_4^\circ - z\ {}^7P_4$? |
| 5561.27 | 5 | — | V | 17976.33 | 6.59 | $a\ {}^7D_5^\circ - z\ {}^{11}G_2$ |
| 5560.20 | 6 | — | V | 17979.98 | 9.99 | $z\ {}^{11}F_7 - e\ {}^9D_6^\circ$ |
| 5559.73 | 150 | 1500 | III A | 17981.50 | 1.54 | $a\ {}^9D_6^\circ - z\ {}^7D_5$ |
| 5550.21 | 100 | 200 | III A | 18012.35 | 2.40 | $a\ {}^7D_5^\circ - 14_4$ |
| 5548.20 | 400*d* | 150 | IV | 18018.87 | 8.82<br>8.96 | $a\ {}^9F_7^\circ - z\ {}^9G_7$<br>$a\ {}^7D_4^\circ - 15_3$ |
| 5534.56 | 100 | 150 | III | 18063.28 | 3.26 | $a\ {}^{11}F_4^\circ - y\ {}^9D_4$ |
| 5533.37 | 50 | 100 | IV | 18067.16 | 7.16 | $a\ {}^7D_4^\circ - y\ {}^9D_5$ |
| 5521.75 | 200 | 250 | III | 18105.18 | 5.21 | $a\ {}^{11}F_5^\circ - y\ {}^9D_2$ |
| 5506.65 | 50 | 8 | IV | 18154.83 | 4.89 | $a\ {}^9F_6^\circ - 44_5$ |
| 5503.75 | 30 | 30 | IV | 18164.40 | 4.40 | $a\ {}^{11}F_5^\circ - y\ {}^9D_2$ |
| 5503.39 | 30 | 250 | III A | 18165.58 | 5.65 | $a\ {}^9D_5^\circ - 7_4$ |
| 5502.56 | 50 | 30 | IV | 18168.32 | 8.38 | $a\ {}^7D_4^\circ - z\ {}^{11}G_2$ |
| 5499.97 | 500 | 150 | IV | 18176.88 | 6.90 | $a\ {}^9F_6^\circ - z\ {}^9G_6$ |
| 5498.75 | 200 | 200 | III | 18180.91 | 0.95 | $a\ {}^{11}F_6^\circ - y\ {}^9D_6$ |
| 5495.40 | 15 | — | V | 18192.00 | 2.02 | $z\ {}^{11}F_6 - e\ {}^9D_5^\circ$ |
| 5493.42 | 100 | 150 | III | 18198.55 | 8.54 | $a\ {}^{11}F_7^\circ - x\ {}^9F_7$ |
| 5492.19 | 1 | 6 | IV A | 18202.63 | 2.65 | $a\ {}^{11}F_4^\circ - 14_4$ |
| 5491.41 | 50 | 10 | IV | 18205.21 | 5.18 | $a\ {}^9F_5^\circ - z\ {}^9G_4$ |
| 5485.36 | 3 | 8 | IV A | 18225.29 | 5.31 | $a\ {}^9F_5^\circ - 34_{1,2}$ |
| 5482.01 | 50 | 30 | IV | 18236.43 | 6.44 | $a\ {}^9F_4^\circ - 40_5$ |
| 5480.23 | 40 | 20 | IV | 18242.35 | 2.33 | $a\ {}^9F_5^\circ - z\ {}^9G_2$ |
| 5475.72 | 60 | 200 | IV A | 18257.38 | 7.41 | $a\ {}^{11}F_6^\circ - y\ {}^9D_4$ |
| 5469.72 | 800 | 25 | IV<br>V E | 18277.40 | 7.48<br>7.45 | $a\ {}^{11}F_5^\circ - y\ {}^9D_2$<br>$a\ {}^{11}F_5^\circ - 18_5$ |
| 5463.260 | 30 | 30 | IV | 18299.02 | 9.06 | $a\ {}^{11}F_7^\circ - y\ {}^9D_4$ |
| 5455.31 | 200 | 60 | III | 18325.68 | 5.69 | $a\ {}^9F_4^\circ - 41_4$ |
| 5453.46 | 1000 | 200 | IV | 18331.90 | 1.89 | $a\ {}^9F_6^\circ - z\ {}^9G_5$ |
| 5452.06 | 8 | 15 | IV A | 18336.61 | 6.67<br>6.79 | $a\ {}^{11}F_7^\circ - y\ {}^9D_2$<br>$a\ {}^7D_4^\circ - z\ {}^{11}G_4$ |
| 5444.94 | 10 | — | V | 18360.58 | 0.68 | $z\ {}^{11}F_5 - e\ {}^9D_4^\circ$ |
| 5443.06 | 1 | — | V | 18366.93 | 6.89 | $a\ {}^9F_6^\circ - 49_6$ |
| 5441.582 | 100 | 100 | III | 18371.92 | 1.93 | $a\ {}^{11}F_6^\circ - z\ {}^{11}G_7$ |

TABLE IX.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 5439.54 | 20 | — | V | 18378.81 | 8.85 | $z\ {}^9P_3 - e\ {}^9D_3^\circ$ |
| 5436.304 | 300 | 200 | III | 18389.75 | 9.74 | $a\ {}^{11}F_7^\circ - z\ {}^{11}G_8$ |
| 5432.00 | 5 | 2 | IV | 18404.32 | 4.42 | $a\ {}^7D_3^\circ - 18_5$ |
| 5425.61 | 12 | 10 | IV | 18426.00 | 6.05 | $a\ {}^{11}F_8^\circ - 23_7$ |
| 5424.67 | 50 | 25 | IV | 18429.19 | 9.21 | $a\ {}^9F_3^\circ - z\ {}^9G_2$ |
| 5421.188 | 200 | 800 | II A | 18441.03 | 1.08 | $a\ {}^9D_4^\circ - z\ {}^{11}P_4$ |
| 5415.69 | 800 | 500 | III | 18459.75 | 9.75 | $a\ {}^{11}F_6^\circ - z\ {}^{11}G_5$ |
| 5413.39 | 200? | 200? | III | 18467.59 | 7.62 | $a\ {}^{11}F_6^\circ - 15_3$ |
| 5413.20 | 800? | 600? | III | 18468.24 | 8.23 | $a\ {}^{11}F_5^\circ - z\ {}^{11}G_4$ |
| 5411.74 | 6 | 2 | IV | 18473.22 | 3.14 | $z\ {}^9P_3 - e\ {}^{11}D_3^\circ$ |
| 5411.197 | 150 | 40 | IV | 18475.08 | 5.12 | $a\ {}^9F_4^\circ - 42_4$ |
| 5401.49 | 2 | 20 | IV A | 18508.28 | 8.21 | $a\ {}^9D_3^\circ - z\ {}^7D_4$ |
| 5399.96 | 20 | 8 | IV | 18513.52 | 3.52 | $a\ {}^9F_3^\circ - 39_7$ |
| 5396.29 | 8*d*? | 2 | IV | 18526.11 | 6.11<br>6.26 | $z\ {}^{11}F_4 - e\ {}^9D_3^\circ$<br>$a\ {}^9D_4^\circ - z\ {}^{11}P_3$ |
| 5391.40 | 2 | — | V | 18542.92 | 2.91 | $a\ {}^9F_4^\circ - 43_3$ |
| 5389.498 | 1000 | 300 | III | 18549.46 | 9.42 | $a\ {}^9F_3^\circ - z\ {}^9G_2$ |
| 5387.05 | 8 | 15 | IV A | 18557.89 | 7.89 | $a\ {}^{11}F_5^\circ - y\ {}^9D_3$ |
| 5384.154 | 250 | 100 | IV | 18567.87 | 7.85 | $a\ {}^9F_4^\circ - 44_3$ |
| 5378.91 | 5 | 2 | IV<br>V E | 18585.97 | 5.85 | $a\ {}^7D_4^\circ - 20_4$ |
| 5377.24 | 12 | 4 | IV | 18591.74 | 1.71 | $a\ {}^9F_5^\circ - 48_5$ |
| 5376.25 | 8*d*? | 15 | IV A | 18595.17 | 5.20 | $a\ {}^7D_3^\circ - z\ {}^{11}G_4$ |
| 5370.745 | 800 | 800 | II | 18614.23 | 4.23 | $a\ {}^{11}F_3^\circ - z\ {}^{11}G_3$ |
| 5370.630 | 150 | | II | 18614.63 | 4.63 | $a\ {}^9F_4^\circ - z\ {}^9G$ |
| 5369.919 | 800 | 600 | II | 18617.09 | 7.04 | $a\ {}^{11}F_4^\circ - z\ {}^{11}G_3$ |
| 5369.612 | 150 | 50 | IV | 18618.16 | 8.14 | $a\ {}^9F_4^\circ - z\ {}^9G_4$ |
| 5368.792 | 80 | 50 | III | 18621.00 | 0.96 | $a\ {}^{11}F_7^\circ - x\ {}^9F_6$ |
| 5367.696 | 100 | 50 | IV | 18624.80 | 4.79 | $a\ {}^9F_3^\circ - z\ {}^9G_1$ |
| 5365.380 | 500 | 200 | III | 18632.84 | 2.78 | $a\ {}^9F_3^\circ - 41_4$ |
| 5361.664 | 250 | 100 | III | 18645.75 | 5.74 | $a\ {}^9F_3^\circ - z\ {}^9G_2$ |
| 5357.59 | 25? | 8 | IV | 18659.93 | 9.91 | $a\ {}^9F_3^\circ - y\ {}^{11}D_7$ |
| 5355.99 | 15 | 30 | IV A | 18665.51 | 5.49 | $a\ {}^{11}F_6^\circ - x\ {}^9F_7$ |
| 5353.26 | 3000 | 800 | III | 18675.03 | 4.97 | $a\ {}^9F_6^\circ - z\ {}^9G_7$ |
| 5350.38 | 4000 | 2000 | III | 18685.08 | 5.10 | $a\ {}^9F_7^\circ - z\ {}^9G_8$ |
| 5348.67 | 2000 | 1200 | II | 18691.05 | 1.04 | $a\ {}^{11}F_3^\circ - z\ {}^{11}G_3$ |
| 5345.676 | 400 | 1500 | II A | 18701.52 | 1.49 | $a\ {}^9D_5^\circ - z\ {}^7D_5$ |
| 5345.126 | 500 | 600 | III | 18703.44 | 3.42 | $a\ {}^{11}F_5^\circ - 15_3$ |
| 5344.66 | 3 | — | V | 18705.08 | 5.25 | $a\ {}^7D_4^\circ - z\ {}^{11}G_5$ |
| 5343.00 | 3000 | 800 | III | 18710.89 | 0.83 | $a\ {}^9F_6^\circ - z\ {}^9G_8$ |
| 5341.814 | 80 | 1000 | II A | 18715.04 | 5.07 | $a\ {}^9D_5^\circ - z\ {}^9F_7$ |
| 5341.168 | 80 | 150 | III A | 18717.30 | 7.29 | $a\ {}^{11}F_5^\circ - 20_4$ |
| 5337.530 | 300 | 80 | III | 18730.06 | 0.05 | $a\ {}^9F_3^\circ - 39_3$ |
| 5333.30 | 2000 | 600 | III | 18744.92 | 4.85 | $a\ {}^9F_4^\circ - z\ {}^9G_4$ |
| 5332.49 | 3*d* | — | V | 18747.76 | 7.77 | $a\ {}^9F_4^\circ - y\ {}^{11}D_4$ |
| 5328.305 | 800 | 300 | III | 18762.49 | 2.47 | $a\ {}^9F_5^\circ - z\ {}^9G_5$ |
| 5327.321 | 1000 | 400 | III | 18765.95 | 5.95 | $a\ {}^9F_2^\circ - z\ {}^9G_2$ |
| 5322.693 | 150 | 80 | IV | 18782.27 | 2.21 | $a\ {}^9F_3^\circ - 42_4$ |
| 5322.366 | 80 | 40 | IV | 18783.42 | 3.42 | $a\ {}^9F_1^\circ - z\ {}^9G_2$ |
| 5321.777 | 4000 | 1500 | II | 18785.50 | 5.45 | $a\ {}^{11}F_4^\circ - z\ {}^{11}G_4$ |
| 5321.496 | 2000 | 600 | II | 18786.49 | 6.50 | $a\ {}^{11}F_3^\circ - z\ {}^{11}G_3$ |
| 5321.25 | 300 | 200 | III | 18787.36 | 7.34 | $a\ {}^{11}F_3^\circ - 16_3$ |
| 5318.27 | 10 | 12 | IV | 18797.89 | 7.80 | $a\ {}^9F_4^\circ - 45_3$? |
| 5311.552 | 12 | 4 | IV | 18821.67 | 1.63 | $a\ {}^9F_6^\circ - y\ {}^{11}D_6$ |
| 5307.30 | 4000 | 3000 | II | 18836.74 | 6.69 | $a\ {}^{11}F_5^\circ - z\ {}^{11}G_5$ |
| 5306.698 | 200 | 300 | III | 18838.88 | 8.84 | $a\ {}^7D_5^\circ - 19_{5,6}$ |
| 5303.615 | 60 | 15 | IV | 18849.83 | 0.00 | $a\ {}^9F_3^\circ - 43_3$? |
| 5302.76 | 3000 | 2000 | II | 18852.87 | 2.84 | $a\ {}^{11}F_5^\circ - z\ {}^{11}G_5$ |
| 5301.67 | 4000 | 2500 | II | 18856.75 | 6.69 | $a\ {}^{11}F_6^\circ - z\ {}^{11}G_6$ |
| 5298.82 | 1 | 10 | IV A | 18866.89 | 6.89 | $a\ {}^9D_4^\circ - z\ {}^7D_3$ |
| 5298.58 | 80 | 30 | IV | 18867.74 | 7.73 | $a\ {}^9F_5^\circ - 39_2$ |
| 5296.335 | 40 | 80 | IV A | 18875.75 | 5.69 | $a\ {}^{11}F_3^\circ - 15_3$ |
| 5283.076 | 3000 | 2000 | II | 18923.11 | 3.08 | $a\ {}^{11}F_7^\circ - z\ {}^{11}G_7$ |
| 5282.484 | 300 | 150 | IV | 18925.25 | 5.23 | $a\ {}^9F_2^\circ - z\ {}^9G_1$ |
| 5275.674 | 5 | 100 | III A | 18949.66 | 9.63 | $a\ {}^9D_3^\circ - 7_4$ |
| 5272.908 | 200 | 300 | III | 18959.60 | 9.61 | $a\ {}^{11}F_2^\circ - 16_2$ |
| 5271.786 | 80 | 80 | III | 18963.64 | 3.66 | $a\ {}^7D_5^\circ - z\ {}^{11}G_5$ |
| 5268.785 | 400 | 2000 | II A | 18974.44 | 4.34<br>4.54 | $a\ {}^9D_4^\circ - z\ {}^7D_4$<br>$a\ {}^{11}F_2^\circ - 17_{1,2}$ |
| 5268.01 | 80 | 60 | IV | 18977.23 | 7.20 | $a\ {}^{11}F_7^\circ - 23_7$ |
| 5263.806 | 100 | 1500 | II A | 18992.39 | 2.39 | $a\ {}^9D_4^\circ - z\ {}^{11}P_4$ |
| 5263.63 | 2 | — | V | 18993.02 | 3.13 | $a\ {}^9F_4^\circ - y\ {}^{11}D_4$ |
| 5260.397 | 40 | 30 | IV | 19004.70 | 4.67 | $a\ {}^9F_4^\circ - 48_5$ |
| 5255.805 | 1500 | 1500 | III | 19021.31 | 1.25 | $a\ {}^{11}F_3^\circ - z\ {}^{11}G_4$ |
| 5254.75 | 300 | 500 | III | 19025.12 | 5.11 | $a\ {}^{11}F_2^\circ - z\ {}^{11}G_2$ |
| 5252.14 | 500 | 500 | V E<br>III | 19034.58 | 4.51 | $a\ {}^{11}F_4^\circ - 20_4$ |
| 5251.180 | 2000 | 2000 | III | 19038.05 | 7.97 | $a\ {}^{11}F_5^\circ - z\ {}^{11}G_5$ |
| 5246.87 | 250*d*? | 30 | IV | 19053.69 | 3.68 | $z\ {}^9P_3 - e\ {}^9S_4^\circ$ |
| 5243.33 | 15 | 10 | IV | 19066.56 | 6.53 | $a\ {}^9F_3^\circ - 43_3$ |
| 5237.454 | 60 | 60 | IV | 19087.94 | 7.91 | $a\ {}^{11}F_6^\circ - x\ {}^9F_6$ |
| 5237.03 | 8*d*? | — | V E | 19089.49 | 9.57 | $z\ {}^9P_5 - e\ {}^9D_5^\circ$ |
| 5233.931 | 400 | 400 | III | 19100.79 | 0.79 | $a\ {}^7D_4^\circ - 22_5$ |
| 5232.805 | 15 | 15 | IV | 19104.90 | 4.89 | $a\ {}^9F_2^\circ - 45_2$ |
| 5229.897 | 12 | 300 | III A | 19115.53 | 5.50 | $a\ {}^9D_5^\circ - z\ {}^7D_2$ |
| 5224.91 | 1 | 1 | IV | 19133.77 | 3.78 | $a\ {}^{11}F_7^\circ - 25_6$ |
| 5224.66 | 8 | 25 | IV A | 19134.69 | 4.67 | $a\ {}^{11}F_6^\circ - x\ {}^9F_5$ |
| 5222.98 | 5 | 6 | IV | 19140.84 | 0.81 | $a\ {}^9F_2^\circ - 46_2$ |
| 5219.40 | 2000 | 2000 | II | 19153.97 | 3.91 | $a\ {}^{11}F_4^\circ - z\ {}^{11}G_5$ |
| 5217.48 | 400 | 2500 | II A | 19161.02 | 1.03 | $a\ {}^9D_6^\circ - z\ {}^{11}P_5$ |
| 5215.68 | 2 | 50 | IV A | 19167.63 | 7.62 | $a\ {}^9D_4^\circ - z\ {}^7D_5$ |
| 5211.024 | 100 | 1200 | II A | 19184.76 | 4.74 | $a\ {}^9D_3^\circ - z\ {}^7D_3$ |
| 5198.15 | 8 | 25 | IV A | 19232.27 | 2.23 | $a\ {}^{11}F_3^\circ - 22_3$ |
| 5197.768 | 1200 | 1500 | II | 19233.63 | 3.63 | $a\ {}^{11}F_3^\circ - z\ {}^{11}G_3$ |
| 5188.23 | 2 | — | V | 19269.04 | 8.97 | $z\ {}^7P_4 - e\ {}^9D_3^\circ$ |
| 5187.881 | 150 | 300 | III A | 19270.34 | 0.31 | $a\ {}^{11}F_5^\circ - 20_4$ |
| 5183.802 | 50 | 800 | III A | 19285.50 | 5.49 | $a\ {}^9D_3^\circ - z\ {}^7D_1$ |
| 5182.01 | 3 | 50 | III A | 19292.17 | 2.19 | $a\ {}^9D_3^\circ - z\ {}^7D_4$ |
| 5177.69 | 8 | 5 | IV | 19308.27 | 8.20 | $a\ {}^9F_7^\circ - x\ {}^7F_6$ |
| 5171.693 | 80 | 1000 | III A | 19330.66 | 0.63 | $a\ {}^9D_2^\circ - z\ {}^7D_2$ |
| 5164.06 | 3 | —? | V? | 19359.23 | 9.20 | $a\ {}^7D_4^\circ - 22_5$ |
| 5163.698 | 150 | 200 | III | 19360.59 | 0.60 | $a\ {}^7D_5^\circ - z\ {}^{11}G_6$ |
| 5158.478 | 150 | 200? | III | 19380.18 | 0.17 | $a\ {}^7D_1^\circ - x\ {}^9F_2$ |
| 5155.845 | 1500 | 1000 | II | 19390.08 | 0.03 | $a\ {}^{11}F_6^\circ - z\ {}^{11}G_7$ |
| 5153.24 | 8 | 100? | III A | 19399.88 | 9.87 | $a\ {}^9D_2^\circ - z\ {}^7D_2$ |
| 5142.685 | 200 | 150 | III | 19439.70 | 9.72 | $a\ {}^7D_2^\circ - x\ {}^9F_4$ |
| 5141.497 | 200 | 150 | III | 19444.18 | 4.15 | $a\ {}^{11}F_6^\circ - 23_7$ |
| 5136.038 | 200 | 200 | III | 19464.85 | 4.85<br>4.81 | $a\ {}^{11}F_5^\circ - x\ {}^9F_4$<br>$a\ {}^7D_1^\circ - x\ {}^9F_2$ |
| 5133.29 | 3 | — | V | 19475.27 | 5.32<br>5.21 | $a\ {}^7D_1^\circ - x\ {}^9F_1$<br>$a\ {}^9F_3^\circ - 47_2$ |
| 5132.223 | 50 | 50? | IV | 19479.33 | 9.34 | $a\ {}^7D_2^\circ - x\ {}^9F_3$ |
| 5120.50 | 8 | —? | V? | 19523.92 | 3.90 | $z\ {}^9P_3 - e\ {}^9D_2^\circ$ |
| 5114.92 | 2 | — | V | 19545.22 | 5.09 | $z\ {}^{11}F_5 - e\ {}^9S_4^\circ$ |
| 5109.27 | 2 | — | V | 19566.83 | 6.82 | $a\ {}^7D_2^\circ - x\ {}^9F_1$ |
| 5103.45 | 2000 | 2000 | II | 19589.14 | 9.12 | $a\ {}^{11}F_7^\circ - z\ {}^{11}G_8$ |
| 5102.763 | 60 | 100 | IV | 19591.79 | 1.82 | $a\ {}^7D_5^\circ - x\ {}^9F_6$ |
| 5100.40 | 1 | — | V | 19600.86 | 0.73 | $a\ {}^{11}F_6^\circ - 25_6$ |
| 5099.273 | 60 | 30 | IV | 19605.19 | 5.22 | $a\ {}^9F_7^\circ - w\ {}^9F_6$ |
| 5097.32 | 12*d* | 3 | IV | 19612.70 | 2.89 | $a\ {}^9F_1^\circ - 47_2$ |
| 5096.931 | 80 | 150 | IV A | 19614.20 | 4.22 | $a\ {}^7D_3^\circ - 24_4$ |
| 5093.659 | 60 | 40 | IV | 19626.80 | 6.77 | $a\ {}^9F_6^\circ - x\ {}^7D_5$ |
| 5076.79 | 3 | — | V | 19692.01 | 2.07 | $a\ {}^7D_5^\circ - x\ {}^9F_5$ |
| 5058.95 | 4 | 10 | IV A | 19761.45 | 1.43 | $z\ {}^9P_3 - e\ {}^9D_2^\circ$ |
| 5047.58 | 20 | 40 | IV A | 19805.97 | 6.01 | $a\ {}^7D_4^\circ - 24_4$ |
| 5044.46 | 3 | — | V | 19818.22 | 8.18 | $a\ {}^9F_5^\circ - 51_3$ |
| 5041.76 | 1 | — | V | 19828.83 | 8.83 | $a\ {}^{11}F_4^\circ - x\ {}^9F_4$ |
| 5040.09 | 1 | — | V | 19835.40 | 5.42 | $a\ {}^{11}F_6^\circ - 26_5$ |
| 5039.093 | 250 | 100 | IV | 19839.32 | 9.34 | $a\ {}^9F_6^\circ - w\ {}^9F_4$ |
| 5034.73 | 2 | — | V | 19856.52 | 6.52 | $a\ {}^{11}F_6^\circ - 27_{5,6}$ |
| 5020.368 | 80 | 60 | IV<br>V E? | 19913.31 | 3.33 | $a\ {}^7D_5^\circ - 28_5$ |
| 5017.209 | 25 | 15 | IV | 19925.85 | 5.87 | $a\ {}^9F_4^\circ - 52_3$ |
| 5015.04 | 1500 | 1500 | II | 19934.48 | 4.48 | $a\ {}^{11}F_6^\circ - z\ {}^{11}G_6$ |
| 5011.741 | 150 | 40 | IV | 19947.60 | 7.57 | $a\ {}^9F_6^\circ - w\ {}^9F_5$ |
| 5004.19 | 15*d* | 25 | IV | 19977.70 | 7.67 | $a\ {}^{11}F_5^\circ - 25_5$ |
| 4999.068 | 400 | 150 | IV | 19998.17 | 8.14 | $a\ {}^9F_4^\circ - w\ {}^9F_3$ |
| 4990.0 | 3 | 1? | IV? | 20034.51 | 4.71 | $a\ {}^9F_5^\circ - 51_3$? |
| 4986.375 | 60 | 80 | IV | 20049.07 | 9.09 | $a\ {}^7D_3^\circ - 28_5$ |
| 4986.19 | 20 | — | V | 20049.82 | 9.93 | $z\ {}^{11}F_4 - e\ {}^9S_4^\circ$ |
| 4975.89 | 5 | — | V | 20091.32 | 1.29 | $a\ {}^{11}F_6^\circ - 29_6$ |
| 4974.253 | 25 | 2 | IV | 20097.93 | 8.05 | $a\ {}^7D_3^\circ - y\ {}^{11}F_7$ |

TABLE IX.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4972.61 | 80 | 150 | IV A | 20104.57 | 4.64 | $a\ {}^7D_5^\circ -$ $25_6$ |
| 4969.165 | 400 | 150 | IV | 20118.51 | 8.47 | $a\ {}^9F_5^\circ - w\ {}^9F_2$ |
| 4958.788 | 800 | 125 | V E IV | 20160.61 | 0.70 | $a\ {}^9F_5^\circ - x\ {}^7D_5$ |
| 4955.432 | 60 | 80 | IV | 20174.27 | 4.25 | $a\ {}^7D_2^\circ -$ $31_3$ |
| 4952.469 | 200 | 800 | II A | 20186.33 | 6.31 | $a\ {}^9D_6^\circ - y\ {}^9P_5$ |
| 4951.585 | 50 | 30 | IV | 20189.94 | 9.93 | $a\ {}^9F_4^\circ - z\ {}^9F_5$ |
| 4950.110 | 150 | 100 | IV | 20195.95 | 5.96 | $a\ {}^9F_2^\circ - w\ {}^9F_1$ |
| 4941.05 | 3 | — | V | 20232.98 | 2.96 | $a\ {}^9F_3^\circ -$ $52_2$ |
| 4939.12 | 3 | 2 | IV | 20240.89 | 0.88 | $a\ {}^7D_4^\circ -$ $28_2$ |
| 4938.607 | 800 | 200 | IV | 20243.00 | 2.97 | $a\ {}^9F_7^\circ - w\ {}^9F_7$ |
| 4936.33 | 200 | 80 | IV | 20252.33 | 2.30 | $a\ {}^9F_4^\circ - w\ {}^9F_4$ |
| 4935.77 | 8 | — | V | 20254.63 | 4.67 | $a\ {}^{11}F_4^\circ -$ $24_4$ |
| 4934.12 | 400? | 200? | IV | 20261.40 | 1.37 | $a\ {}^9F_6^\circ - w\ {}^9F_6$ |
| 4923.463 | 30 | 25 | IV | 20305.25 | 5.23 | $a\ {}^9F_3^\circ - w\ {}^9F_3$ |
| 4919.45 | 8 | 5 | IV | 20321.82 | 1.84 | $a\ {}^{11}F_5^\circ - x\ {}^9P_4$ |
| 4916.598 | 80 | 40 | IV | 20333.61 | 3.64 | $a\ {}^9F_1^\circ - w\ {}^9F_1$ |
| 4915.833 | 100 | 100 | IV | 20336.77 | 6.79 | $a\ {}^7D_4^\circ -$ $29_5$ |
| 4910.123 | 100 | 150 | IV | 20360.43 | 0.43 | $a\ {}^7D_5^\circ -$ $27_{5,6}$ |
| 4902.80 | 50 | 10 | IV | 20390.83 | 0.77 | $a\ {}^9F_4^\circ -$ $55_5$ |
| 4901.5 | 4 | — | V | 20396.24 | 6.29 | $a\ {}^9F_6^\circ -$ $56_5$ |
| 4889.99 | 1 | — | V | 20444.25 | 4.04 | $a\ {}^9F_4^\circ -$ $53_3$? |
| 4888.724 | 30 | 15 | IV | 20449.54 | 9.49 | $a\ {}^9F_4^\circ -$ $52_3$ |
| 4883.19 | 250 | 80 | IV | 20472.72 | 2.68 | $a\ {}^9F_1^\circ - w\ {}^9F_2$ |
| 4881.36 | 200 | 60? | IV | 20480.39 | 0.28 | $a\ {}^9F_7^\circ - x\ {}^9D_6$ |
| 4881.084 | 250 | 80 | IV | 20481.56 | 1.50 | $a\ {}^9F_6^\circ - w\ {}^9F_5$ |
| 4878.94 | 4 | 3 | IV A | 20490.55 | 0.47 | $a\ {}^{11}F_3^\circ -$ $24_4$ |
| 4877.563 | 40 | 50 | IV | 20496.33 | 6.33 | $a\ {}^7D_4^\circ - x\ {}^9P_5$ |
| 4877.08 | 4 | — | V | 20498.26 | 8.28 | $a\ {}^9F_6^\circ - z\ {}^9F_6$ |
| 4871.505 | 200 | 100 | IV | 20521.82 | 1.76 | $a\ {}^9F_2^\circ - w\ {}^9F_2$ |
| 4864.56 | 6d? | — | V | 20551.12 | 0.99 | $a\ {}^9F_5^\circ - x\ {}^7F_4$ |
| 4863.12 | 25 | 15 | IV | 20557.20 | 7.11 | $a\ {}^{11}F_7^\circ -$ $36_{6,7}$ |
| 4862.592 | 250 | 100 | IV | 20559.44 | 9.39 | $a\ {}^9F_2^\circ - w\ {}^9F_4$ |
| 4861.783 | 100 | 50 | IV | 20562.86 | 2.79 | $a\ {}^9F_4^\circ - x\ {}^7D_4$ |
| 4860.47 | 5 | — | V | 20568.41 | 8.32 | $a\ {}^{11}F_3^\circ - x\ {}^9F_2$ |
| 4859.224 | 60 | 50 | IV | 20573.69 | 3.66 | $a\ {}^9F_4^\circ - x\ {}^7D_5$ |
| 4856.48 | 5 | 8 | IV | 20585.31 | 5.31 | $a\ {}^{11}F_4^\circ - x\ {}^9P_2$ |
| 4854.14 | 40 | 60 | IV | 20595.23 | 5.20 | $a\ {}^7D_5^\circ -$ $29_5$ |
| 4852.644 | 15 | 20 | IV | 20601.58 | 1.59 | $a\ {}^{11}F_5^\circ -$ $30_5$ |
| 4846.84 | 5 | 2 | IV | 20626.25 | 6.27 | $a\ {}^7D_4^\circ - y\ {}^{11}F_3$ |
| 4846.47 | 10 | 15 | IV | 20627.83 | 7.77 | $a\ {}^{11}F_5^\circ - x\ {}^9P_5$ |
| 4843.82 | 20 | 20 | IV | 20639.11 | 9.06 | $a\ {}^{11}F_4^\circ - x\ {}^9P_4$ |
| 4835.257 | 200 | 600 | I A | 20675.66 | 5.71 | $a\ {}^9D_5^\circ - y\ {}^9P_4$ |
| 4832.00 | 4 | 1 | IV | 20689.60 | 9.54 | $a\ {}^{11}F_4^\circ -$ $28_3$ |
| 4824.00 | 4 | — | V | 20723.91 | 3.86 | $a\ {}^9F_5^\circ - x\ {}^7F_5$ |
| 4819.797 | 30 | 50 | IV | 20741.98 | 2.02 | $a\ {}^7D_5^\circ -$ $32_4$ |
| 4816.832 | 150 | 50 | IV | 20754.75 | 4.71 | $a\ {}^9F_6^\circ - x\ {}^9D_5$ |
| 4816.182 | 10 | 40 | IV A | 20757.56 | 7.58 | $a\ {}^{11}F_2^\circ - x\ {}^9P_3$ |
| 4814.44 | 25 | 10 | IV | 20765.06 | 5.03 | $a\ {}^9F_5^\circ -$ $54_4$ |
| 4809.968 | 15 | 15 | IV | 20784.37 | 4.31 | $a\ {}^{11}F_7^\circ -$ $37_5$ |
| 4808.013 | 30 | 10 | IV | 20792.82 | 2.79 | $z\ {}^9P_4 - e\ {}^9S_4^\circ$ |
| 4807.836 | 10 | 2 | IV | 20793.59 | 3.62 | $a\ {}^7D_1^\circ -$ $34_{1,2}$ |
| 4807.451 | 500 | 500 | III | 20795.25 | 5.30<br>5.18 | $a\ {}^9F_5^\circ - w\ {}^9F_6$<br>$a\ {}^{11}F_6^\circ - y\ {}^{11}F_7$ |
| 4789.14 | 6 | 8 | IV | 20874.76 | 4.86 | $a\ {}^{11}F_5^\circ - x\ {}^9P_4$ |
| 4788.68 | 2 | — | V | 20876.76 | 6.82 | $a\ {}^7D_5^\circ - y\ {}^{11}F_4$ |
| 4786.753 | 200 | 100 | IV | 20885.17 | 5.12 | $a\ {}^7D_2^\circ -$ $34_{1,2}$ |
| 4784.622 | 600 | 800 | III | 20894.47 | 4.46<br>4.38 | $a\ {}^9F_4^\circ - w\ {}^9F_5$<br>$a\ {}^{11}F_7^\circ - y\ {}^{11}F_6$ |
| 4783.558 | 30 | 15 | IV | 20899.12 | 9.12 | $a\ {}^9F_6^\circ - w\ {}^9F_7$ |
| 4781.917 | 300 | 600 | I A | 20906.29 | 6.26 | $a\ {}^9D_5^\circ - y\ {}^9P_5$ |
| 4780.987 | 60 | 20 | IV | 20910.36 | 0.37 | $a\ {}^9F_5^\circ - x\ {}^9D_4$ |
| 4775.64 | 8 | 15 | IV A | 20933.76 | 3.81 | $a\ {}^7D_4^\circ -$ $32_4$ |
| 4775.44 | 8 | 8 | IV | 20934.64 | 4.60 | $a\ {}^{11}F_6^\circ -$ $33_5$ |
| 4773.09 | 15d? | 10 | IV | 20944.95 | 4.99 | $a\ {}^{11}F_6^\circ - x\ {}^9P_5$ |
| 4771.8 | 1 | — | V | 20950.6 | 0.46 | $a\ {}^{11}F_4^\circ -$ $31_3$ |
| 4768.760 | 15 | 10 | IV | 20963.97 | 3.95 | $a\ {}^9F_6^\circ - x\ {}^7F_4$ |
| 4767.240 | 1000 | 600 | II | 20970.65 | 0.63 | $a\ {}^{11}F_6^\circ - y\ {}^{11}F_5$ |
| 4766.07 | 2 | — | V | 20975.80 | 5.75 | $a\ {}^9F_4^\circ - x\ {}^7D_4$ |
| 4763.825 | 125 | 40 | IV | 20985.68 | 5.59 | $a\ {}^9F_6^\circ - x\ {}^9D_3$ |
| 4760.740 | 150 | 400 | II A | 20999.28 | 9.29 | $a\ {}^9D_6^\circ -$ $12_5$ |
| 4758.696 | 800 | 400 | II | 21008.30 | 8.26 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_4$ |
| 4758.262 | 200 | 600 | I A | 21010.22 | 0.16 | $a\ {}^9D_5^\circ - y\ {}^9P_3$ |
| 4745.820 | 150 | 150 | III | 21065.30 | 5.25 | $a\ {}^{11}F_5^\circ -$ $32_4$ |
| 4743.65 | 1000 | 800 | II | 21074.94 | 4.93 | $a\ {}^{11}F_4^\circ - y\ {}^{11}F_3$ |
| 4738.55 | 1 | 4 | IV A | 21097.62 | 7.61 | $a\ {}^{11}F_3^\circ -$ $28_3$ |
| 4735.746 | 400 | 400 | II | 21110.11 | 0.06 | $a\ {}^{11}F_3^\circ - y\ {}^{11}F_2$ |
| 4730.120 | 30 | 40 | III | 21135.23 | 5.23 | $a\ {}^7D_5^\circ - y\ {}^{11}F_4$ |
| 4728.643 | 100 | 250 | II A | 21141.82 | 1.84 | $a\ {}^9D_6^\circ - y\ {}^9P_4$ |
| 4720.560 | 4 | 2 | IV | 21178.02 | 7.99 | $a\ {}^9F_4^\circ -$ $54_4$ |
| 4718.714 | 15 | 30 | III A | 21186.31 | 6.26 | $a\ {}^{11}F_5^\circ -$ $31_3$ |
| 4717.35 | 6d | — | V E V | 21192.43 | 2.22 | $a\ {}^7D_5^\circ -$ $32_4$ |
| 4709.785 | 200 | 500 | I A | 21226.47 | 6.46 | $a\ {}^9D_5^\circ -$ $11_4$ |
| 4707.892 | 5 | 100 | III A | 21235.01 | 5.01 | $a\ {}^9D_5^\circ -$ $9_2$ |
| 4707.03 | 2 | — | V | 21239.90 | 9.99 | $a\ {}^7D_4^\circ -$ $35_5$ |
| 4704.286 | 6 | 25 | III A | 21251.29 | 1.26 | $a\ {}^{11}F_6^\circ -$ $37_6$ |
| 4697.422 | 300 | 500 | II | 21282.34 | 2.33 | $a\ {}^{11}F_2^\circ - y\ {}^{11}F_2$ |
| 4696.769 | 10 | 5 | IV | 21285.29 | 5.25 | $z\ {}^9P_3 - e\ {}^9S_4^\circ$ |
| 4695.977 | 15 | 20 | IV | 21288.89 | 8.80<br>8.64 | $a\ {}^9F_3^\circ - x\ {}^9D_3$<br>$(a\ {}^9F_3^\circ - x\ {}^9D_3)$ |
| 4695.126 | 10 | 15 | IV | 21292.74 | 2.68 | $a\ {}^9F_6^\circ - x\ {}^9D_3$ |
| 4694.330 | 800 | 600 | II | 21296.35 | 6.32 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_5$ |
| 4691.164 | 50 | 50 | III | 21310.72 | 0.73 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_3$ |
| 4688.388 | 4 | —? | V? | 21323.34 | 3.33 | $a\ {}^9F_4^\circ - x\ {}^9D_4$ |
| 4688.125 | 100 | 250 | I A | 21324.54 | 4.53 | $a\ {}^9D_5^\circ -$ $10_3$ |
| 4687.92 | 1 – | — | V | 21325.47 | 5.48 | $a\ {}^{11}F_7^\circ - y\ {}^{11}F_4$ |
| 4687.36 | 2 | 40 | III A | 21328.02 | 8.01 | $a\ {}^9D_5^\circ - y\ {}^9P_3$ |
| 4683.334 | 500 | 250 | III | 21346.36 | 6.33 | $a\ {}^{11}F_7^\circ - y\ {}^{11}F_7$ |
| 4683.073 | 60 | 80 | III | 21347.53 | 7.57 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_5$ |
| 4682.2 | 1 | — | V | 21351.5 | 1.73 | $a\ {}^7D_1^\circ - z\ {}^9G_2$ |
| 4680.651 | 8 | 20 | IV | 21358.59 | 8.53 | $a\ {}^{11}F_6^\circ -$ $31_3$ |
| 4680.043 | 200 | 200 | III | 21361.36 | 1.33 | $a\ {}^{11}F_6^\circ - y\ {}^{11}F_6$ |
| 4679.176 | 100 | 30 | IV | 21365.32 | 5.28 | $a\ {}^9F_7^\circ -$ $65_6$ |
| 4677.82 | 1 | 1 | IV | 21371.52 | 1.43 | $a\ {}^{11}F_5^\circ -$ $35_5$ |
| 4677.629 | 6 | 100 | III A | 21372.38 | 2.39 | $a\ {}^9D_5^\circ - y\ {}^9P_5$ |
| 4674.07 | 2 | 2 | IV | 21388.66 | 8.61 | $a\ {}^9F_4^\circ -$ $57_3$ |
| 4671.44 | 3 | 2? | IV? | 21400.70 | 0.67 | $a\ {}^9F_6^\circ -$ $62_5$ |
| 4658.608 | 15 | 100 | III A | 21459.65 | 9.63 | $a\ {}^9D_5^\circ - y\ {}^9P_4$ |
| 4654.765 | 5 | 50 | III A | 21477.36 | 7.38 | $a\ {}^9D_6^\circ - z\ {}^9D_5$ |
| 4653.544 | 200 | 150 | III | 21483.00 | 3.00 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_3$ |
| 4652.313 | 20 | 15 | III | 21488.68 | 8.66 | $a\ {}^9F_4^\circ - x\ {}^7P_4$ |
| 4649.74 | 4 | 6 | IV | 21500.58 | 0.52 | $a\ {}^9F_4^\circ -$ $58_3$ |
| 4648.703 | 25 | 20 | III | 21505.37 | 5.33 | $a\ {}^9F_5^\circ - x\ {}^9D_2$ |
| 4647.645 | 60 | 150 | II A | 21510.26 | 0.30<br>9.21 | $a\ {}^9D_6^\circ - z\ {}^9D_6$<br>$(a\ {}^9F_2^\circ - x\ {}^9D_3)$ |
| 4645.999 | 40 | 40 | III | 21517.89 | 7.79 | $a\ {}^9F_6^\circ -$ $63_5$ |
| 4640.543 | 5 | 60 | III A | 21543.19 | 3.14 | $a\ {}^9D_5^\circ - y\ {}^9P_3$ |
| 4637.24 | 15 | 30 | III A | 21558.53 | 8.52 | $a\ {}^7D_4^\circ -$ $38_4$ |
| 4636.638 | 250 | 200 | III | 21561.33 | 1.28 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_4$ |
| 4635.91 | 10 | 8 | IV | 21564.72 | 4.60 | $a\ {}^9F_4^\circ -$ $59_3$ |
| 4630.512 | 15 | 15 | III | 21589.86 | 9.80 | $a\ {}^9F_5^\circ -$ $61_4$ |
| 4624.417 | 60 | 100 | III | 21618.31 | 8.27 | $a\ {}^{11}F_5^\circ -$ $32_4$ |
| 4622.311 | 10 | 15 | III | 21628.16 | 8.20 | $a\ {}^{11}F_4^\circ -$ $37_5$ |
| 4622.187 | 4 | 10 | III A | 21628.74 | 8.76 | $a\ {}^{11}F_5^\circ -$ $33_5$ |
| 4621.78 | 2 | 2 | IV | 21630.65 | 0.42 | $a\ {}^9F_3^\circ - x\ {}^9D_4$ |
| 4619.140 | 25 | 20 | III | 21643.01 | 3.01 | $a\ {}^9F_7^\circ - x\ {}^9D_2$ |
| 4614.497 | 300 | 200 | III | 21664.78 | 4.79 | $a\ {}^{11}F_4^\circ - y\ {}^{11}F_5$ |
| 4613.33 | 1 | 3 | IV A | 21670.26 | 0.36 | $a\ {}^9F_5^\circ - x\ {}^9D_5$ |
| 4608.581 | 8 | 100 | III A | 21692.60 | 2.59 | $a\ {}^9D_5^\circ -$ $11_4$ |
| 4607.92 | 1 | 3 | IV A | 21695.71 | 5.70 | $a\ {}^9F_5^\circ -$ $57_3$ |
| 4607.19 | 1 | 2 | IV A | 21699.14 | 9.20 | $a\ {}^7D_5^\circ - z\ {}^9G_2$ |
| 4602.929 | 200 | 200 | II | 21719.23 | 9.24 | $a\ {}^9D_5^\circ -$ $12_5$ |
| 4598.897 | 300 | 200 | III | 21738.27 | 8.27 | $a\ {}^{11}F_5^\circ - y\ {}^{11}F_6$ |
| 4595.337 | 6 | 25 | III A | 21755.12 | 5.17 | $a\ {}^7D_5^\circ -$ $37_6$ |
| 4589.544 | 6 | 30 | III A | 21782.57 | 2.56 | $a\ {}^7D_5^\circ -$ $41_4$ |
| 4588.06 | 2 | 6 | IV A | 21789.62 | 9.61 | $a\ {}^9F_2^\circ - x\ {}^7F_2$ |
| 4584.265 | 25 | 30 | III | 21807.65 | 7.61 | $a\ {}^9F_3^\circ -$ $58_3$ |
| 4583.07 | 300 | 200 | III | 21813.34 | 3.28 | $a\ {}^{11}F_6^\circ - y\ {}^{11}F_7$ |
| 4582.332 | 20? | 20 | III A | 21816.85 | 6.93 | $a\ {}^7D_4^\circ -$ $38_4$ |
| 4581.294 | 250 | 250 | II | 21821.80 | 1.80 | $a\ {}^9D_6^\circ - z\ {}^9D_4$ |
| 4575.907 | 150 | 150 | III | 21847.48 | 7.47 | $a\ {}^{11}F_7^\circ - y\ {}^{11}F_5$ |

TABLE IX.—*Continued.*

| King Intensity | | | | Wave number | | |
|---|---|---|---|---|---|---|
| I A | Arc | Furnace | T C | Observed | Calc. | Desig. |
| 4573.809 | 100 | 150 | II | 21857.51 | 7.51 | *a* $^9D_5^\circ$ – $10_3$ |
| 4572.43 | 4 | 15 | III A | 21864.10 | 4.02 | *a* $^7D_2^\circ$ – $43_2$ |
| 4572.20 | 20*d*? | 50 | III A | 21865.20 | 5.24 | *a* $^7D_3^\circ$ – *y* $^{11}F_6$ |
| 4570.837 | 4 | 10 | IV A | 21871.72 | 1.69 | *a* $^9F_3^\circ$ – $59_2$ |
| 4568.04 | 2 | 10 | IV A | 21885.11 | 5.10 | *a* $^7D_4^\circ$ – $40_3$ |
| 4566.62 | 1 | 4 | IV A | 21891.92 | 1.86 | *a* $^9F_2^\circ$ – *x* $^7F_1$ |
| 4564.590 | 6 | 15 | IV A | 21901.65 | 1.62 | *a* $^9F_4^\circ$ – *x* $^7P_4$ |
| 4559.24 | 1 – | 1 | IV | 21927.35 | 7.29 | *a* $^9F_1^\circ$ – *x* $^7F_2$ |
| 4557.73 | 1 – | — | V | 21934.62 | 4.60 | *a* $^9F_5^\circ$ – $62_5$ |
| 4550.18 | 1 | 5 | III A | 21971.01 | 1.01 | *a* $^{11}F_6^\circ$ – $44_5$ |
| 4549.49 | 4 | 10 | III A | 21974.35 | 4.35 | *a* $^7D_4^\circ$ – $41_4$ |
| 4544.23 | 20 | 40 | III A | 21999.78 | 9.78 | *a* $^7D_3^\circ$ – $43_3$ |
| 4543.605 | 4 | 8 | IV A | 22002.81 | 2.76 | *a* $^9F_4^\circ$ – $61_4$ |
| 4542.74 | 12 | 25 | III A | 22007.00 | 6.92 | *a* $^{11}F_6^\circ$ – *z* $^9G_7$ |
| 4542.031 | 200 | 300 | I | 22010.43 | 0.44 | *a* $^9D_2^\circ$ – $11_4$ |
| 4540.76 | 1 | 4 | IV A | 22016.59 | 6.54 | *a* $^{11}F_5^\circ$ – $40_5$ |
| 4539.76 | 2 | 2 | IV | 22021.44 | 1.43 | *a* $^9F_4^\circ$ – $65_6$ |
| 4539.21 | 3 | 5 | IV | 22024.11 | 4.14 | *a* $^9F_3^\circ$ – $58_5$ |
| 4537.813 | 600 | 600 | I | 22030.89 | 0.87 | *a* $^9D_4^\circ$ – *z* $^9D_3$ |
| 4533.514 | 12 | 12 | IV | 22051.78 | 1.72 | *a* $^9F_5^\circ$ – $63_5$ |
| 4531.821 | 30 | 40 | III | 22060.02 | 0.00 | *a* $^{11}F_7^\circ$ – *z* $^9G_8$ |
| 4531.138 | 10 | 30 | III A | 22063.34 | 3.33 | *a* $^7D_1^\circ$ – $46_2$ |
| 4530.00 | 1 | 4 | IV A | 22068.89 | 8.88 | *a* $^7D_2^\circ$ – *y* $^{11}D_3$ |
| 4526.03 | 5 | 8 | IV | 22088.24 | 8.22 | *a* $^9F_5^\circ$ – $59_5$ |
| 4520.79 | 5 | 8 | IV | 22113.85 | 3.82 | *a* $^9F_1^\circ$ – *x* $^7D_2$ |
| 4519.655 | 500 | 500 | I | 22119.40 | 9.39 | *a* $^9D_3^\circ$ – *z* $^9D_2$ |
| 4518.767 | 5 | 15 | III A | 22123.75 | 3.78 | *a* $^7D_4^\circ$ – $42_4$ |
| 4516.68 | 2 | 3 | IV | 22133.97 | 3.87 | *a* $^9F_1^\circ$ – *x* $^7D_1$ |
| 4514.74 | ? | 4 | IV A | 22143.48 | 3.51 | *a* $^7D_3^\circ$ – $40_5$ |
| 4513.805 | 6 | 15 | III A | 22148.07 | 8.01 | *a* $^{11}F_6^\circ$ – *z* $^9G_5$ |
| 4512.43 | 4 | 12 | III A | 22154.81 | 4.83 | *a* $^7D_2^\circ$ – $46_3$ |
| 4507.064 | 8*d* | 25 | III A | 22181.19 | 1.20 | *a* $^7D_1^\circ$ – $47_2$ |
| 4506.212 | 400 | 300 | I | 22185.39 | 5.37 | *a* $^9D_4^\circ$ – $12_5$ |
| 4504.960 | 12 | 20 | III A | 22191.55 | 1.57 | *a* $^7D_4^\circ$ – $43_3$ |
| 4503.790 | 20 | 100 | II A | 22197.32 | 7.33 | *a* $^9D_5^\circ$ – *z* $^9D_3$ |
| 4502.304 | 2 | 8 | III A | 22204.64 | 4.64 | *a* $^7D_3^\circ$ – *y* $^{11}D_3$ |
| 4501.47 | 3 | 3 | IV | 22208.76 | 8.71 | *a* $^9F_2^\circ$ – *x* $^7P_3$ |
| 4499.910 | 5 | 15 | III A | 22216.46 | 6.51 | *a* $^7D_4^\circ$ – $44_5$ |
| 4497.127 | 300 | 200 | I | 22230.20 | 0.25 | *a* $^9D_3^\circ$ – *z* $^9D_4$ |
| 4496.615 | 10 | 30 | III A | 22232.73 | 2.76 | *a* $^7D_2^\circ$ – $41_4$ |
| 4492.032 | 8*d*? | 4 | IV | 22255.42 | 5.22 | *a* $^{11}F_5^\circ$ – $42_4$ |
| 4489.74 | 3 | 4 | III | 22266.78 | 6.80 | *a* $^7D_4^\circ$ – *z* $^9G_4$ |
| 4488.543 | 12 | 40 | III A | 22272.72 | 2.70 | *a* $^7D_2^\circ$ – $47_2$ |
| 4486.900 | 200 | 300 | II | 22280.87 | 0.86 | *a* $^9D_5^\circ$ – *y* $^9F_5$ |
| 4485.479 | 25 | 125 | II A | 22287.93 | 7.93 | *a* $^9D_4^\circ$ – *z* $^9D_4$ |
| 4476.3 | 3 | 2 | IV | 22333.6 | 3.76 | *a* $^{11}F_4^\circ$ – $40_5$ |
| 4476.116 | 300 | 200 | I | 22334.55 | 4.52 | *a* $^9D_2^\circ$ – *z* $^9D_2$ |
| 4475.09 | 2 | 5 | IV A | 22339.67 | 9.65 | *a* $^{11}F_4^\circ$ – *z* $^9G_3$ |
| 4473.4 | 1 | 2 | IV A | 22348.11 | 7.95 | *a* $^{11}F_5^\circ$ – $44_5$ |
| 4473.280 | 20 | 150 | II A | 22348.71 | 8.72 | *a* $^9D_4^\circ$ – *z* $^9D_3$ |
| 4466.604 | 500† | 50 | III | 22382.11 | 2.19 | *a* $^7D_3^\circ$ – $42_4$ |
| 4464.34 | 3 | 2 | IV | 22393.46 | 3.51 | *a* $^7D_4^\circ$ – *z* $^9G_5$ |
| 4463.39 | 1 | 5 | IV A | 22398.23 | 8.24 | *a* $^{11}F_5^\circ$ – *z* $^9G_4$ |
| 4461.361 | 20 | 30 | III | 22408.42 | 8.46 | *a* $^7D_3^\circ$ – $47_2$ |
| 4452.726 | 25 | 30 | III | 22451.88 | 1.85 | *a* $^9F_7^\circ$ – $71_8$ |
| 4448.17 | 5 | 15 | III A | 22474.86 | 4.92 | *a* $^7D_5^\circ$ – $44_5$ |
| 4437.886 | 8 | ? | IV? | 22526.95 | 6.95 | *a* $^{11}F_6^\circ$ – *z* $^9G_6$ |
| 4431.759 | 40 | 100 | III A | 22558.09 | 8.07 | *a* $^{11}F_7^\circ$ – *z* $^9G_7$ |
| 4430.630 | 600 | 600 | I | 22563.84 | 3.85 | *a* $^9D_2^\circ$ – *z* $^9D_2$ |
| 4428.944 | 6 | 15 | III A | 22572.43 | 2.44 | *a* $^{11}F_4^\circ$ – $42_4$ |
| 4428.34 | 1 | 3 | IV A | 22575.51 | 5.45 | *a* $^{11}F_5^\circ$ – *z* $^9G_3$ |
| 4422.406 | 600 | 600 | I | 22605.80 | 5.78 | *a* $^9D_5^\circ$ – *z* $^9D_4$ |
| 4415.65 | 8 | 15 | III A | 22640.38 | 0.23 | *a* $^{11}F_4^\circ$ – $43_3$ |
| 4415.42 | 40 | 12 | IV | 22641.56 | 1.79 | (*a* $^7D_4^\circ$ – *y* $^{11}D_4$)? |
| 4414.732 | 400 | 600 | I | 22645.09 | 5.08 | *a* $^9D_5^\circ$ – *y* $^9F_4$ |
| 4414.16 | 500 | 300 | III | 22648.02 | 8.01 | *a* $^{11}F_6^\circ$ – *y* $^{11}D_7$ |
| 4413.44 | 20 | 10 | III | 22651.72 | 1.92 | *a* $^7D_5^\circ$ – *z* $^9G_5$ |
| 4412.05 | 1 | — | V | 22658.86 | 8.81 | *a* $^{11}F_5^\circ$ – $41_4$ |
| 4411.157 | 400 | 500 | I | 22663.43 | 3.46 | *a* $^9D_4^\circ$ – *z* $^9D_3$ |
| 4409.254 | 100 | 100 | III | 22673.22 | 3.20 | *a* $^{11}F_6^\circ$ – *z* $^9G_8$ |
| 4403.14 | 200 | 150 | III | 22704.71 | 4.73 | *a* $^{11}F_7^\circ$ – *y* $^{11}D_8$ |
| 4401.857 | 800 | 1000 | I | 22711.33 | 1.39 | *a* $^9D_4^\circ$ – *y* $^9F_5$ |
| 4400.757 | 40 | 50 | III | 22717.00 | 6.94 | *a* $^{11}F_4^\circ$ – $49_5$ |
| 4392.063 | 150 | 200 | III | 22761.97 | 1.93 | *a* $^{11}F_6^\circ$ – *y* $^{11}D_5$ |
| 4389.884 | 50 | 100 | III A | 22773.27 | 3.23 | *a* $^{11}F_5^\circ$ – *y* $^{11}D_4$ |
| 4378.561 | 40 | 150 | III A | 22832.16 | 2.20 | *a* $^7D_2^\circ$ – $51_3$ |
| 4376.073 | 20 | 150 | III A | 22845.13 | 5.09 | *a* $^{11}F_4^\circ$ – *y* $^{11}D_3$ |
| 4373.833 | 800 | 1500 | I | 22856.84 | 6.82 | *a* $^9D_4^\circ$ – *y* $^9F_3$ |
| 4370.180 | 40 | 180 | III A | 22875.95 | 6.03 | *a* $^{11}F_5^\circ$ – $43_3$ |
| 4366.521 | 4 | 15 | IV A | 22895.12 | 5.12 | *a* $^{11}F_4^\circ$ – $45_3$ |
| 4365.22 | 1 | 1 | IV | 22901.94 | 1.95 | *a* $^7D_1^\circ$ – *w* $^9F_1$ |
| 4364.84 | 1 | 3 | IV A | 22903.93 | 3.89 | *a* $^{11}F_6^\circ$ – *z* $^9G_6$ |
| 4363.35 | 1 | 4 | IV A | 22911.75 | 1.74 | *a* $^7D_5^\circ$ – $48_5$ |
| 4352.669 | 15 | 8 | IV, V E | 22967.97 | 7.96 | *a* $^7D_3^\circ$ – $51_3$ |
| 4347.84 | 2 | 6 | IV A | 22993.48 | 3.45 | *a* $^7D_5^\circ$ – *w* $^9F_1$ |
| 4346.624 | 600 | 1000 | I | 22999.91 | 9.94 | *a* $^9D_4^\circ$ – *y* $^9F_2$ |
| 4346.458 | 1500 | 2000 | I | 23000.80 | 0.81 | *a* $^9D_5^\circ$ – *y* $^9F_5$ |
| 4341.90 | 2 | 4 | IV A | 23024.94 | 5.02 | *a* $^{11}F_6^\circ$ – *z* $^9G_7$ |
| 4340.8 | 1 | 1 | IV | 23030.78 | 0.86 | *a* $^7D_5^\circ$ – *z* $^9G_6$ |
| 4338.88 | 2 | 4 | IV A | 23040.97 | 0.99 | *a* $^7D_1^\circ$ – *w* $^9F_2$ |
| 4337.510 | 80 | 100 | V E, III | 23048.24 | 8.30 | *a* $^{11}F_3^\circ$ – $43_3$ |
| 4332.93 | 2 | 3 | IV | 23072.60 | 2.63 | *a* $^7D_4^\circ$ – $50_4$ |
| 4331.379 | 100 | 250 | III A | 23080.87 | 0.89 | *a* $^{11}F_5^\circ$ – *y* $^{11}D_3$ |
| 4329.580 | 200 | 300 | III | 23090.46 | 0.45 | *a* $^{11}F_4^\circ$ – *y* $^{11}D_4$ |
| 4328.937 | 25 | 60 | III A | 23093.89 | 3.88 | *a* $^{11}F_5^\circ$ – $49_5$ |
| 4327.42 | 3 | 2 | IV | 23101.98 | 1.99 | *a* $^{11}F_4^\circ$ – $48_5$ |
| 4327.125 | 1500 | 2000 | V E, I | 23103.56 | 3.64 | *a* $^9D_5^\circ$ – *y* $^9F_1$ |
| 4325.693 | 600 | 2000 | I A | 23111.18 | 1.21 | *a* $^9D_4^\circ$ – *y* $^9F_4$ |
| 4322.014 | 4 | 20 | III A | 23130.88 | 0.92 | *a* $^{11}F_5^\circ$ – $45_3$ |
| 4321.198 | 150 | 800 | II A | 23135.25 | 5.27 | *a* $^9D_4^\circ$ – $13_{5,5}$ |
| 4320.519 | 150 | 250 | III | 23138.88 | 8.87 | *a* $^{11}F_5^\circ$ – *y* $^{11}D_5$ |
| 4316.63 | 4 | 5 | IV | 23159.73 | 9.75 | *a* $^7D_4^\circ$ – $51_3$ |
| 4314.400 | 400 | 300 | III | 23171.70 | 1.68 | *a* $^{11}F_6^\circ$ – *y* $^{11}D_6$ |
| 4313.845 | 2000 | 2000 | I | 23174.68 | 4.67 | *a* $^9D_5^\circ$ – *y* $^9F_2$ |
| 4309.290 | 200 | 200 | III | 23199.18 | 9.16 | *a* $^{11}F_7^\circ$ – *y* $^{11}D_7$ |
| 4308.38 | 20 | 20 | III | 23204.08 | 4.07 | *a* $^{11}F_5^\circ$ – $50_4$ |
| 4306.340 | 1500 | 1500 | I | 23215.07 | 5.07 | *a* $^9D_5^\circ$ – *y* $^9F_3$ |
| 4305.2 | 1 | 3 | IV A | 23221.2 | 1.20 | *a* $^9F_6^\circ$ – $68_{4,5}$ |
| 4304.62 | 3 | 8 | IV A | 23224.34 | 4.35 | *a* $^{11}F_7^\circ$ – *z* $^9G_8$ |
| 4299.293 | 200 | 200 | III | 23253.12 | 3.16 | *a* $^{11}F_5^\circ$ – *y* $^{11}D_3$ |
| 4296.95 | 60 | 50 | III | 23265.79 | 5.84 | *a* $^7D_5^\circ$ – *y* $^{11}D_5$ |
| 4296.505 | 6 | 8 | IV | 23268.21 | 8.25 | *a* $^7D_3^\circ$ – *w* $^9F_2$ |
| 4290.061 | 80 | 60 | III | 23303.16 | 3.19 | *a* $^{11}F_5^\circ$ – $45_3$ |
| 4287.11 | 4 | 6 | IV | 23319.20 | 9.25 | *a* $^7D_2^\circ$ – *w* $^9F_3$ |
| 4286.122 | 300 | 400 | II | 23324.57 | 4.59 | *a* $^9D_4^\circ$ – *y* $^9D_5$ |
| 4285.819 | 400 | 200 | III | 23326.22 | 6.25 | *a* $^{11}F_5^\circ$ – *y* $^{11}D_4$ |
| 4284.944 | 30 | 40 | III | 23330.98 | 1.04 | *a* $^7D_5^\circ$ – $50_4$ |
| 4274.167 | 300 | 500 | II | 23389.81 | 9.80 | *a* $^9D_2^\circ$ – *y* $^9F_3$ |
| 4270.28 | 60 | 50 | III | 23411.10 | 1.10 | *a* $^{11}F_4^\circ$ – $49_5$ |
| 4267.002 | 600 | 500 | II | 23429.09 | 9.06 | *a* $^9D_2^\circ$ – *y* $^9F_4$ |
| 4266.595 | 800 | 600 | II | 23431.32 | 1.34 | *a* $^9D_5^\circ$ – *y* $^9F_6$ |
| 4262.31 | ? | 5 | IV | 23454.88 | 5.01 | *a* $^7D_5^\circ$ – *w* $^9F_3$ |
| 4262.092 | 2500† | 150 | V E, III | 23456.08 | 6.09 | *a* $^{11}F_4^\circ$ – *y* $^{11}D_4$ |
| 4260.116 | 800 | 800 | II | 23466.96 | 6.94 | *a* $^9D_4^\circ$ – *y* $^9F_2$ |
| 4250.277 | 40 | 40 | III A | 23521.29 | 1.29 | *a* $^{11}F_4^\circ$ – $50_4$ |
| 4245.341 | 125 | 100 | III | 23548.63 | 8.62 | *a* $^{11}F_6^\circ$ – *y* $^{11}D_6$ |
| 4240.681 | 25 | 30 | III | 23574.51 | 4.53 | *a* $^7D_5^\circ$ – $52_3$ |
| 4227.72 | 4 | 6 | IV | 23646.78 | 6.80 | *a* $^7D_4^\circ$ – *w* $^9F_2$ |
| 4225.850 | 3000 | 2000 | I | 23657.24 | 7.28 | *a* $^9D_6^\circ$ – *y* $^9F_7$ |
| 4225.259 | 20 | 8 | III | 23660.55 | 0.58 | *a* $^9F_7^\circ$ – $78_6$ |
| 4225.028 | 200 | 500 | II A | 23661.84 | 1.85 | *a* $^9D_6^\circ$ – $18_6$ |
| 4224.270 | 40 | 40 | III | 23666.09 | 6.11 | *a* $^{11}F_6^\circ$ – *y* $^{11}D_7$ |
| 4222.58 | 5 | 10 | III A | 23675.56 | 5.59 | *a* $^7D_5^\circ$ – *y* $^{11}D_6$ |
| 4216.6 | 3 | 8 | IV A | 23709.14 | 9.17 | *a* $^7D_3^\circ$ – *w* $^9F_4$ |
| 4215.256 | 20 | 5? | IV? | 23716.70 | 6.67 | *a* $^9F_7^\circ$ – $80_6$ |
| 4208.08 | 25 | 25 | III | 23757.14 | 7.09 | *a* $^{11}F_5^\circ$ – $50_4$ |

† Blend with Gd II line.

TABLE IX.—*Continued.*

| King Intensity I A | Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4206.667 | 10 | 15 | III | 23765.12 | 5.15 | $a\ {}^7D_2^o - 53_2$ |
| 4191.626 | 800 | 600 | I | 23850.39 | 0.39 | $a\ {}^9D_3^o - y\ {}^9D_4$ |
| 4190.776 | 1500 | 1000 | I | 23855.23 | 5.22 | $a\ {}^9D_3^o - 13_{3,4}$ |
| 4182.767 | 60 | 50 | III A | 23900.91 | 0.96 | $a\ {}^7D_4^o - w\ {}^9F_4$ |
| | | | | | 0.91 | $a\ {}^7D_3^o - 53_3$ |
| 4175.538 | 2000 | 1000 | I | 23942.28 | 2.29 | $a\ {}^9D_5^o - y\ {}^9D_5$ |
| 4171.708 | 100 | 50 | III | 23964.27 | 4.26 | $a\ {}^9F_6^o - 76_5$ |
| 4169.52 | 5 | 5 | IV | 23976.84 | 6.82 | $a\ {}^{11}F_6^o - x\ {}^7D_5$ |
| 4167.267 | 150 | 250 | II | 23989.80 | 9.78 | $a\ {}^9D_5^o - 14_4$ |
| 4157.784 | 250*d* | 300 | II | 24044.52 | 4.54 | $a\ {}^9D_5^o - y\ {}^9D_5$ |
| 4149.478 | 80 | 40 | III | 24092.64 | 2.70 | $a\ {}^7D_4^o - 53_3$ |
| 4148.86 | 150 | 400 | II A | 24096.23 | 6.27 | $a\ {}^9D_6^o - 19_{5,6}$ |
| 4140.58 | 10 | 10 | III | 24144.42 | 4.50 | $a\ {}^{11}F_3^o - w\ {}^9F_2$ |
| | | | | | 4.47 | $a\ {}^{11}F_7^o - w\ {}^9F_6$ |
| 4138.028 | 20 | 20 | III A | 24159.31 | 9.37 | $a\ {}^7D_5^o - w\ {}^9F_4$ |
| 4134.162 | 1000 | 600 | I | 24181.90 | 1.86 | $a\ {}^9D_4^o - y\ {}^9D_5$ |
| 4127.27 | 10 | 8 | IV | 24222.28 | 2.32 | $a\ {}^7D_4^o - x\ {}^7D_5$ |
| 4125.778 | 40 | 20 | IV | 24231.04 | 1.07 | $a\ {}^{11}F_6^o - w\ {}^9F_7$ |
| 4121.028 | 8 | 8 | V E | 24258.97 | 8.99 | $a\ {}^{11}F_5^o - 52_3$ |
| | | | III | | | |
| 4118.50 | 2 | — | V | 24273.86 | 3.87 | $a\ {}^{11}F_7^o - 55_6$ |
| 4113.61 | 4 | 4 | IV | 24302.72 | 2.82 | $a\ {}^7D_2^o - x\ {}^9D_2$ |
| 4112.935 | 50 | 30 | III | 24306.70 | 6.70 | $a\ {}^7D_3^o - x\ {}^9D_3$ |
| 4111.25 | 3 | 6 | III A | 24316.67 | 6.77 | $a\ {}^{11}F_5^o - w\ {}^9F_2$ |
| | | | | | 6.52 | $a\ {}^9D_4^o - y\ {}^9D_4$ |
| 4104.987 | 60 | 40 | III | 24353.77 | 3.76 | $a\ {}^{11}F_5^o - x\ {}^7D_5$ |
| 4100.265 | 800 | 1000 | I | 24381.83 | 1.80 | $a\ {}^9D_5^o - 18_5$ |
| 4093.720 | 250 | 300 | III A | 24420.79 | 0.82 | $a\ {}^7D_3^o - x\ {}^7F_4$ |
| 4092.713 | 1500 | 1500? | I | 24426.80 | 6.83 | $a\ {}^9D_6^o - x\ {}^9F_7$ |
| 4091.968 | 4 | 5 | III | 24431.25 | 1.26 | $a\ {}^{11}F_5^o - 52_3$ |
| 4091.748 | 30 | 20 | III A | 24432.56 | 2.62 | $a\ {}^7D_3^o - x\ {}^7D_4$ |
| 4090.95 | 5 | 5 | IV | 24437.32 | 7.37 | $a\ {}^7D_2^o - x\ {}^7F_3$ |
| 4090.74 | 8 | 5 | III | 24438.58 | 8.58 | $a\ {}^7D_3^o - x\ {}^9D_2$ |
| 4090.412 | 800 | 800 | I | 24440.54 | 0.52 | $a\ {}^9D_3^o - y\ {}^9D_2$ |
| 4090.09 | 2 | 2 | IV | 24442.47 | 2.46 | $a\ {}^7D_3^o - x\ {}^9D_2$ |
| 4087.83 | 6 | 25 | III A | 24455.98 | 5.91 | $a\ {}^9D_4^o - 14_4$ |
| 4083.702 | 800 | 600 | III | 24480.70 | 0.73 | $a\ {}^7D_5^o - x\ {}^7D_5$ |
| 4080.780 | 15 | 6 | IV | 24498.23 | 8.19 | $a\ {}^9F_5^o - 76_5$ |
| 4080.530 | 100 | 500 | II A | 24499.73 | 9.71 | $a\ {}^9D_5^o - y\ {}^9D_5$ |
| 4078.700 | 3000 | 2000 | I | 24510.72 | 0.67 | $a\ {}^9D_4^o - y\ {}^9D_5$ |
| 4069.83 | 5 | — | V | 24564.14 | 4.08 | $a\ {}^9F_6^o - 81_5$ |
| 4068.740 | 150 | 150 | III | 24570.72 | 0.71 | $a\ {}^7D_2^o - x\ {}^7D_3$ |
| 4068.44 | 400 | 2 | IV | 24572.53 | 2.58 | $a\ {}^9D_5^o - z\ {}^{11}G_4$ |
| 4068.349 | | 300 | III | 24573.08 | 3.13 | $a\ {}^7D_3^o - x\ {}^7F_3$ |
| 4066.036 | 100 | 150 | III | 24587.06 | 7.10 | $a\ {}^7D_2^o - x\ {}^7F_2$ |
| 4064.24 | 1 | — | V E | 24597.92 | 7.85 | $(a\ {}^7D_1^o - x\ {}^7F_1)$ |
| 4062.01 | 3 | 2 | IV | 24611.43 | 1.42 | $a\ {}^{11}F_6^o - w\ {}^9F_6$ |
| 4061.824 | 40 | 50 | III | 24612.55 | 2.61 | $a\ {}^7D_4^o - x\ {}^7F_4$ |
| 4061.163 | 30 | 150 | III A | 24616.56 | 6.63 | $a\ {}^9D_4^o - 22_5$ |
| 4060.93 | 5 | 10 | III A | 24617.97 | 8.03 | $a\ {}^9D_6^o - z\ {}^{11}G_6$ |
| 4059.875 | 500 | 400 | III | 24624.37 | 4.41 | $a\ {}^7D_4^o - x\ {}^7D_4$ |
| 4058.219 | 2500 | 2000 | I | 24634.41 | 4.37 | $a\ {}^9D_3^o - y\ {}^9D_4$ |
| 4054.724 | 400 | 1000 | I A | 24655.65 | 5.65 | $a\ {}^9D_3^o - y\ {}^9D_2$ |
| 4053.642 | 2500 | 1500 | I | 24662.24 | 2.24 | $a\ {}^9D_5^o - y\ {}^9D_6$ |
| 4051.62 | 15 | 20 | IV | 24674.54 | 4.56 | $a\ {}^{11}F_5^o - w\ {}^9F_5$ |
| 4050.370 | 60 | 125 | III A | 24682.16 | 2.13 | $a\ {}^7D_1^o - x\ {}^7D_2$ |
| 4049.54 | 20 | 40 | III A | 24687.21 | 7.21 | $a\ {}^7D_1^o - z\ {}^7F_0$ |
| 4049.199 | 200 | 150 | III | 24689.29 | 9.35 | $a\ {}^7D_2^o - z\ {}^7F_1$ |
| 4048.864 | 20 | 30 | III | 24691.34 | 1.34 | $a\ {}^{11}F_6^o - z\ {}^7F_6$ |
| 4047.089 | 200 | 150 | III | 24702.16 | 2.18 | $a\ {}^7D_1^o - x\ {}^7D_1$ |
| 4046.38 | 4 | 4 | IV | 24706.49 | 6.47 | $a\ {}^7D_2^o - x\ {}^7D_2$ |
| 4045.858 | 80 | 100 | III | 24709.68 | 9.72 | $a\ {}^7D_2^o - 57_2$ |
| 4045.009 | 800 | 1200 | I | 24714.87 | 4.84 | $a\ {}^9D_2^o - y\ {}^9D_2$ |
| 4044.025 | 20 | 100 | III A | 24720.88 | 0.88 | $a\ {}^9D_4^o - 15_3$ |
| 4043.709 | 250 | 200 | III | 24722.81 | 2.86 | $a\ {}^7D_2^o - x\ {}^7F_2$ |
| 4038.30 | 6 | 6 | IV | 24755.92 | 5.85 | $a\ {}^{11}F_5^o - x\ {}^7D_4$ |
| 4036.839 | 150 | 200 | III | 24764.89 | 4.92 | $a\ {}^7D_4^o - x\ {}^7F_3$ |
| 4036.68 | 2 | — | V | 24765.86 | 5.91 | $a\ {}^9F_5^o - 75_2$ |
| 4035.400 | 200 | 400 | II A | 24773.72 | 3.63 | $a\ {}^7D_2^o - x\ {}^7D_2$ |
| | | | | | 3.76 | $a\ {}^9D_3^o - 14_4$ |
| 4034.352 | 8 | 8 | III | 24780.16 | 0.20 | $a\ {}^7D_3^o - x\ {}^9D_4$ |

| King Intensity I A | Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 4034.02 | 3 | 3 | IV | 24782.19 | 2.22 | $a\ {}^{11}F_7^o - w\ {}^9F_7$ |
| 4033.490 | 600 | 300 | III | 24785.45 | 5.48 | $a\ {}^7D_4^o - x\ {}^7F_5$ |
| 4032.161 | 5 | 6 | IV | 24793.61 | 3.68 | $a\ {}^7D_2^o - x\ {}^7D_1$ |
| 4030.883 | 800 | 300 | III | 24801.48 | 1.53 | $a\ {}^7D_5^o - w\ {}^9F_5$ |
| 4028.153 | 800 | 300 | III | 24818.28 | 8.31 | $a\ {}^7D_5^o - x\ {}^7F_6$ |
| 4027.611 | 200 | 300 | III | 24821.62 | 1.63 | $a\ {}^7D_3^o - 58_3$ |
| | | | | | 1.64 | $a\ {}^9D_5^o - 20_4$ |
| 4026.80 | 3 | 4 | IV | 24826.62 | 6.65 | $a\ {}^7D_4^o - 54_4$ |
| 4023.738 | 8 | 10 | IV | 24845.51 | 5.48 | $a\ {}^7D_3^o - 57_3$ |
| 4023.346 | 1000 | 1000 | I | 24847.94 | 7.93 | $a\ {}^9D_4^o - 18_5$ |
| 4023.143 | 1000 | 1000 | I | 24849.19 | 9.25 | $a\ {}^9D_6^o - x\ {}^9F_6$ |
| 4022.91 | 1 | — | V | 24850.63 | 0.66 | $a\ {}^9F_5^o - 78_5$ |
| 4019.732 | 200 | 300 | II | 24870.28 | 0.30 | $a\ {}^9D_4^o - z\ {}^{11}G_2$ |
| 4017.713 | 400 | 100 | III | 24882.78 | 2.82 | $a\ {}^7D_5^o - x\ {}^7D_4$ |
| 4017.247 | 200 | 80 | III | 24885.66 | 5.71 | $a\ {}^7D_3^o - 59_3$ |
| 4015.695 | 5 | — | V | 24895.28 | 5.28 | $a\ {}^9F_5^o - 79_4$ |
| 4015.583 | 50 | 100 | III A | 24895.97 | 6.01 | $a\ {}^9D_5^o - x\ {}^9F_5$ |
| 4015.220 | 50 | 50 | III | 24898.22 | 8.26 | $a\ {}^7D_4^o - x\ {}^7D_3$ |
| 4013.426 | 60 | 50 | III | 24909.36 | 9.39 | $a\ {}^7D_3^o - x\ {}^7D_2$ |
| 4013.14 | 1 | — | V | 24911.13 | 1.15 | $a\ {}^9F_4^o - 76_5$ |
| 4008.331 | 300 | 500 | II A | 24941.02 | 1.04 | $a\ {}^9D_5^o - z\ {}^{11}G_5$ |
| 4006.963 | 60 | 200 | III A | 24949.53 | 9.54 | $a\ {}^9D_3^o - z\ {}^{11}G_3$ |
| 4003.362 | 20 | 25 | IV | 24971.98 | 1.99 | $a\ {}^7D_4^o - x\ {}^9D_4$ |
| 4001.68 | 8 | 5 | IV | 24982.46 | 2.44 | $a\ {}^9F_5^o - 75_2$ |
| 4000.176 | 50 | 40 | IV A | 24991.86 | 1.78 | $a\ {}^{11}F_4^o - w\ {}^9F_4$ |
| | | | | | 1.84 | $a\ {}^7D_4^o - 56_5$ |
| 3995.45 | 5 | 4 | IV | 25021.42 | 1.47 | $a\ {}^7D_5^o - 59_3$ |
| 3992.92 | 4 | 2 | IV | 25037.27 | 7.27 | $a\ {}^7D_4^o - 57_3$ |
| 3992.691 | 600 | 500 | II | 25038.71 | 8.71 | $a\ {}^9D_4^o - z\ {}^{11}G_4$ |
| | | | | | 8.73 | $a\ {}^9D_5^o - 15_5$ |
| 3987.835 | 600 | 600 | II | 25069.20 | 9.21 | $a\ {}^9D_3^o - z\ {}^{11}G_2$ |
| 3985.671 | 8 | 4 | IV | 25082.81 | 2.91 | $a\ {}^{11}F_4^o - x\ {}^9D_5$ |
| 3985.32 | 3 | 3 | IV A | 25085.02 | 5.06 | $a\ {}^7D_5^o - 54_4$ |
| 3983.26 | 1 | — | V | 25097.99 | 8.01 | $a\ {}^9F_5^o - 81_5$ |
| 3982.35 | 2 | — | V | 25103.73 | 3.43 | $a\ {}^{11}F_5^o - x\ {}^9D_4$ |
| 3980.122 | 4 | 4 | IV | 25117.78 | 7.76 | $a\ {}^{11}F_5^o - 55_6$ |
| 3979.751 | 6 | 3 | IV | 25120.12 | 0.12 | $a\ {}^9F_1^o - 75_2$ |
| 3979.333 | 1000 | 800 | II | 25122.76 | 2.65 | $a\ {}^9D_5^o - 16_2$ |
| 3975.15 | ? | 5 | IV | 25149.20 | 9.18 | $a\ {}^7D_1^o - 58_2$ |
| 3974.812 | 400 | 300 | II | 25151.33 | 1.37 | $a\ {}^9D_6^o - z\ {}^{11}G_7$ |
| 3972.706 | 500 | 400 | I | 25164.67 | 4.67 | $a\ {}^9D_2^o - z\ {}^{11}G_2$ |
| 3969.003 | 800 | 500 | I | 25188.14 | 8.15 | $a\ {}^9D_2^o - z\ {}^{11}G_3$ |
| 3966.275 | 600 | 400 | II | 25205.47 | 5.49 | $a\ {}^9D_6^o - 23_7$ |
| 3965.04 | 20 | 20 | III | 25213.32 | 3.26 | $a\ {}^7D_4^o - 59_3$ |
| 3964.98 | 1 | 1 | IV | 25213.70 | 3.58 | $a\ {}^{11}F_6^o - x\ {}^7F_5$ |
| 3962.35 | 1 | — | V | 25230.44 | 0.40 | $a\ {}^7D_5^o - x\ {}^9D_4$ |
| 3960.108 | 150 | 100 | III | 25244.72 | 4.73 | $a\ {}^7D_5^o - 55_6$ |
| 3959.25 | 3 | 3 | IV | 25250.19 | 0.25 | $a\ {}^7D_5^o - 56_5$ |
| 3958.680 | 50 | 150 | III A | 25253.82 | 3.86 | $a\ {}^9D_2^o - 15_2$ |
| 3953.367 | 500 | 400 | II | 25287.76 | 7.77 | $a\ {}^9D_4^o - 20_4$ |
| 3949.16 | 4 | — | V | 25314.70 | 4.83 | $a\ {}^{11}F_5^o - x\ {}^9D_2$ |
| 3946.972 | 30 | 20 | IV | 25328.73 | 8.72 | $a\ {}^7D_4^o - 60_5$ |
| 3945.75 | 8 | 40 | III A | 25336.58 | 6.58 | $a\ {}^9D_5^o - 22_5$ |
| 3945.541 | 800*d* | 800 | I | 25337.92 | 7.98 | $a\ {}^9D_5^o - z\ {}^{11}G_6$ |
| | | | | | 7.78 | $a\ {}^9D_2^o - 16_2$ |
| 3943.617 | 150 | 200 | III | 25350.29 | 0.26 | $a\ {}^7D_4^o - x\ {}^9D_5$ |
| 3943.236 | 200 | 200 | II | 25352.73 | 2.71 | $a\ {}^9D_2^o - 17_{1,2}$ |
| 3942.633 | 400 | 400 | I | 25356.61 | 6.56 | $a\ {}^9D_5^o - z\ {}^{11}G_4$ |
| 3942.35 | 3 | 1 | IV | 25358.43 | 8.49 | $a\ {}^7D_2^o - x\ {}^7F_1$ |
| 3941.800 | 300 | 300 | II | 25361.97 | 2.07 | $a\ {}^9D_6^o - 25_6$ |
| 3935.385 | 200 | 300 | I | 25403.31 | 3.28 | $a\ {}^9D_2^o - z\ {}^{11}G_3$ |
| 3934.790 | 600? | 500 | I | 25407.15 | 7.17 | $a\ {}^9D_6^o - z\ {}^{11}G_5$ |
| 3926.684 | 60 | 30 | III | 25459.60 | 9.63 | $a\ {}^7D_4^o - 61_4$ |
| 3926.49 | 2 | — | V | 25460.86 | 0.85 | $a\ {}^9F_5^o - 77_2$ |
| 3922.63 | 1 | — | V | 25485.91 | 5.93 | $a\ {}^{11}F_4^o - 57_3$ |
| 3921.85 | 3 | — | V | 25490.98 | 0.98 | $a\ {}^{11}F_5^o - x\ {}^9D_2$ |
| 3918.77 | 4 | 1 | IV | 25511.01 | 0.97 | $a\ {}^9F_4^o - 81_5$ |
| | | | | | 1.11 | $a\ {}^{11}F_5^o - 54_4?$ |
| 3912.75 | 30 | 15 | IV | 25550.26 | 0.28 | $a\ {}^7D_4^o - x\ {}^7P_4$ |
| 3905.646 | 600 | 200 | II | 25596.74 | 6.76 | $a\ {}^9D_6^o - 26_6$ |
| 3904.290 | 300 | 150 | II | 25605.62 | 5.62 | $a\ {}^9D_5^o - 20_4$ |

TABLE IX.—*Continued.*

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3902.709 | 400 | 200 | II | 25616.00 | 5.96 | $a\ {}^9D_5^\circ - x\ {}^9F_5$ |
| 3897.321 | 30? | 30 | IV | 25651.41 | 1.42 | $a\ {}^7D_4^\circ -$ $61_4$ |
| 3893.36 | 2 | — | V | 25677.51 | 7.38 | $a\ {}^9F_5^\circ -$ $77_5$ |
| 3892.723 | 15 | 10 | IV | 25681.71 | 1.72 | $a\ {}^{11}F_6^\circ - x\ {}^7P_4$ |
| 3887.734 | 50 | 100 | III A | 25714.66 | 4.67 | $a\ {}^9D_4^\circ -$ $21_3$ |
| 3874.46 | 80 | 100 | II | 25802.76 | 2.71 | $a\ {}^9D_4^\circ -$ $22_5$ |
| 3873.57 | 100 | 50 | III | 25808.69 | 8.69 | $a\ {}^7D_5^\circ - x\ {}^7P_4$ |
| 3866.989 | 500 | 150 | I | 25852.61 | 2.63 | $a\ {}^9D_5^\circ -$ $29_5$ |
| 3865.37 | 3 | — | V | 25863.44 | 3.42 | $a\ {}^{11}F_5^\circ - x\ {}^9D_5$ |
| 3864.79 | 40 | 30 | III | 25867.32 | 7.30 | $a\ {}^9D_5^\circ - x\ {}^9F_4$ |
| 3858.45 | 60 | 30 | III | 25909.82 | 9.83 | $a\ {}^7D_5^\circ -$ $61_4$ |
| 3846.49 | 80 | 60 | IV | 25990.38 | 0.39 | $a\ {}^7D_5^\circ - x\ {}^9D_6$ |
| 3843.275 | 500 | 150 | I | 26012.12 | 2.17 | $a\ {}^9D_4^\circ - x\ {}^9P_3$ |
| 3840.265 | 60 | 100 | II | 26032.51 | 2.52 | $a\ {}^9D_5^\circ -$ $21_3$ |
| 3838.900 | 30 | 50 | III | 26041.77 | 1.80 | $a\ {}^9D_5^\circ -$ $24_4$ |
| 3832.97 | 100 | 50? | III | 26082.06 | 2.09<br>2.02 | $a\ {}^9D_4^\circ - x\ {}^9F_5$<br>$a\ {}^9D_5^\circ -$ $25_6$ |
| 3828.38 | 15 | 6 | III | 26113.33 | 3.34 | $a\ {}^7D_4^\circ -$ $63_5$ |
| 3824.15 | 50 | 40 | IV | 26142.21 | 2.22 | $a\ {}^7D_5^\circ - x\ {}^7P_3$ |
| 3808.79 | 6 | 50 | III A | 26247.63 | 7.65 | $a\ {}^9D_5^\circ -$ $21_3$ |
| 3804.39 | 80 | 80 | III | 26277.99 | 7.98 | $a\ {}^7D_5^\circ - x\ {}^7P_3$ |
| 3798.66 | 6 | 10 | IV | 26316.63 | 6.71 | $a\ {}^9D_5^\circ -$ $26_6$? |
| 3796.37 | 2500 | 200 | IV E | 26333.50 | 3.43 | $(a\ {}^9D_5^\circ - x\ {}^9F_4)$ |
| 3795.75 | 50 | 250 | II A | 26337.80 | 7.81 | $a\ {}^9D_5^\circ -$ $27_{5,6}$ |
| 3783.05 | 1200 | 600 | I | 26426.22 | 6.19 | $a\ {}^9D_5^\circ - x\ {}^9P_4$ |
| 3776.83 | 100 | 100 | III | 26469.74 | 9.77 | $a\ {}^7D_5^\circ - x\ {}^7P_3$ |
| 3773.45 | 100 | 80 | III | 26493.45 | 3.42 | $a\ {}^7D_5^\circ - x\ {}^7P_2$ |
| 3771.38 | 20 | 100 | III A | 26507.99 | 7.93 | $a\ {}^9D_4^\circ -$ $24_4$ |
| 3771.26 | 40 | 150 | II A | 26508.83 | 8.81 | $a\ {}^9D_4^\circ - x\ {}^9F_3$ |
| 3762.20 | 400 | 400 | I | 26572.67 | 2.58 | $a\ {}^9D_5^\circ -$ $29_5$ |
| 3760.47 | 60 | 60 | III | 26584.89 | 4.92 | $a\ {}^7D_2^\circ - x\ {}^7P_2$ |
| 3757.94 | 600 | 500 | I | 26602.79 | 2.77 | $a\ {}^9D_5^\circ - x\ {}^9P_3$ |
| 3751.10 | 40 | 150 | II A | 26651.30 | 1.28 | $a\ {}^9D_3^\circ - x\ {}^9F_4$ |
| 3744.83 | 400 | 400 | I | 26695.92 | 5.94 | $a\ {}^9D_4^\circ -$ $33_5$ |
| 3741.36 | 30 | 50 | IV | 26720.68 | 0.68 | $a\ {}^7D_5^\circ - x\ {}^7P_2$ |
| 3739.76 | 500 | 600 | I | 26732.11 | 2.12<br>1.97 | $a\ {}^9D_5^\circ - x\ {}^9P_3$<br>$(a\ {}^9D_4^\circ - y\ {}^{11}F_5)$ |
| 3736.44 | 40 | 100 | IV A | 26755.86 | 5.83 | $a\ {}^9D_5^\circ -$ $35_5$ |
| 3732.67 | 100 | 250 | II A | 26782.89 | 2.84 | $a\ {}^9D_4^\circ -$ $26_5$ |
| 3732.324 | 150 | 300 | II A | 26785.37 | 5.40 | $a\ {}^9D_6^\circ -$ $36_{6,7}$ |
| 3726.70 | 8 | 80 | III A | 26825.79 | 5.78 | $a\ {}^9D_5^\circ -$ $24_4$ |
| 3726.57 | 40 | 200 | II A | 26826.73 | 6.66 | $a\ {}^9D_5^\circ - x\ {}^9F_3$ |
| 3719.81 | 4 | 15 | II A | 26875.48 | 5.39 | $a\ {}^7D_5^\circ -$ $65_6$ |
| 3717.48 | 1500 | 800 | I | 26892.32 | 2.32 | $a\ {}^9D_4^\circ - x\ {}^9P_4$ |
| 3715.92 | 50 | 300 | II A | 26903.61 | 3.63<br>3.52 | $a\ {}^9D_5^\circ - x\ {}^9F_2$<br>$a\ {}^7D_5^\circ -$ $67_6$? |
| 3713.57 | 1200 | 1000 | I | 26920.64 | 0.62 | $a\ {}^9D_5^\circ - x\ {}^9P_3$ |
| 3710.51 | 3 | 30 | IV A | 26942.84 | 2.80 | $a\ {}^9D_4^\circ -$ $28_3$ |
| 3700.93 | 50 | 200 | II A | 27012.58 | 2.60 | $a\ {}^9D_5^\circ -$ $37_5$ |
| 3697.35 | 25 | 150 | III A | 27038.73 | 8.71 | $a\ {}^9D_4^\circ -$ $29_5$ |
| 3697.27 | 2 | — | V | 27039.32 | 9.28 | $a\ {}^7D_5^\circ -$ $67_5$ |
| 3696.93 | 50 | 200 | II A | 27041.80 | 1.79 | $a\ {}^9D_5^\circ - x\ {}^9F_4$ |
| 3687.28 | 20 | 100 | III A | 27112.57 | 2.61 | $a\ {}^9D_5^\circ - y\ {}^{11}F_4$ |
| 3686.442 | 30 | 200 | II A | 27118.74 | 8.76 | $a\ {}^9D_5^\circ - x\ {}^9F_2$ |
| 3685.91 | 5 | 40 | III A | 27122.65 | 2.67 | $a\ {}^9D_6^\circ - y\ {}^{11}F_5$ |
| 3685.01 | 30 | 200 | II A | 27129.27 | 9.27 | $a\ {}^9D_5^\circ - x\ {}^9F_1$ |
| 3684.13 | 1000 | 1000 | I | 27135.75 | 5.75 | $a\ {}^9D_5^\circ - x\ {}^9P_2$ |
| 3679.54 | 20 | 150 | III A | 27169.60 | 9.60 | $a\ {}^9D_5^\circ -$ $32_4$ |
| 3679.21 | 100 | 300 | II A | 27172.04 | 2.07 | $a\ {}^9D_4^\circ -$ $30_4$ |
| 3675.68 | 8 | — | V | 27198.13 | 8.25 | $(a\ {}^9D_6^\circ - x\ {}^9P_4)$ |
| 3674.05 | 400 | 400 | I | 27210.20 | 0.17 | $a\ {}^9D_5^\circ - x\ {}^9P_4$ |
| 3672.27 | 3 | 2 | IV | 27223.39 | 3.38 | $a\ {}^7D_4^\circ -$ $66_4$ |
| 3667.25 | 3 | 30 | IV A | 27260.65 | 0.65 | $a\ {}^9D_5^\circ -$ $28_3$ |
| 3658.188 | 50 | 250 | III A | 27328.18 | 8.19 | $a\ {}^9D_6^\circ - y\ {}^{11}F_5$ |
| 3656.74 | 4 | 5 | IV | 27339.00 | 8.99 | $a\ {}^7D_5^\circ -$ $69_5$ |
| 3648.48 | 150*d* | 500 | II A | 27400.90 | 0.94 | $a\ {}^9D_6^\circ -$ $40_5$ |
| 3647.20 | 5 | 5 | IV<br>V E | 27410.51 | 0.33 | $a\ {}^7D_5^\circ -$ $70_4$ |
| 3646.480 | 30 | 300 | II A | 27415.92 | 5.89 | $a\ {}^9D_5^\circ -$ $33_5$ |
| 3642.57 | 25 | 300 | III A | 27445.35 | 5.37 | $a\ {}^9D_5^\circ - y\ {}^{11}F_5$ |
| 3641.68 | 10 | 100 | IV A | 27452.06 | 1.92 | $a\ {}^9D_5^\circ - y\ {}^{11}F_4$ |

| I A | King Intensity Arc | Furnace | T C | Wave number Observed | Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3638.53 | 3 | 30 | IV A | 27475.83 | 5.78<br>5.78 | $a\ {}^9D_5^\circ -$ $28_5$<br>$a\ {}^9D_5^\circ -$ $35_5$ |
| 3637.74 | 5 | 15 | IV A | 27481.79 | 1.79 | $a\ {}^7D_5^\circ -$ $66_4$ |
| 3636.66 | 1 | 15 | IV A | 27489.95 | 9.92 | $a\ {}^9D_2^\circ -$ $30_4$ |
| 3632.48 | 4 | 40 | IV A | 27521.58 | 1.57 | $a\ {}^9D_5^\circ -$ $31_3$ |
| 3625.50 | 4 | 40 | IV A | 27574.57 | 4.62 | $a\ {}^9D_6^\circ - y\ {}^{11}F_7$ |
| 3624.95 | ? | 80 | IV A | 27578.75 | 8.74 | $a\ {}^9D_4^\circ - y\ {}^{11}F_4$ |
| 3621.88 | 2 | 5 | IV A | 27602.13 | 2.12 | $a\ {}^7D_4^\circ -$ $70_4$ |
| 3617.47 | 1 | 20 | IV A | 27635.78 | 5.73 | $a\ {}^9D_4^\circ -$ $32_4$ |
| 3616.12 | 1 | 25 | IV A | 27646.09 | 6.04 | $a\ {}^9D_5^\circ - y\ {}^{11}F_5$ |
| 3614.21 | 100 | 400 | II A<br>V E | 27660.70 | 0.50 | $a\ {}^9D_2^\circ - y\ {}^{11}F_2$ |
| 3606.98 | 5 | 20 | IV A | 27716.15 | 6.15 | $a\ {}^7D_4^\circ -$ $72_{4,5}$ |
| 3604.87 | 500 | 800 | I | 27732.37 | 2.35<br>2.55 | $a\ {}^9D_4^\circ -$ $44_5$<br>$a\ {}^9D_5^\circ -$ $37_6$ |
| 3604.31 | 2 | 25 | IV A | 27736.68 | 6.70 | $a\ {}^9D_2^\circ -$ $31_3$ |
| 3596.841 | 30 | 300 | II A | 27794.28 | 4.31 | $a\ {}^9D_5^\circ -$ $38_4$ |
| 3590.59 | 10 | 100 | II A | 27842.66 | 2.62 | $a\ {}^9D_5^\circ - y\ {}^{11}F_6$ |
| 3588.207 | 15 | 150 | II A | 27861.15 | 1.17 | $a\ {}^9D_2^\circ - y\ {}^{11}F_2$ |
| 3585.523 | 12 | 100 | II A | 27882.01 | 2.02 | $a\ {}^9D_4^\circ -$ $33_5$ |
| 3583.65 | 20*d*? | 150 | II A | 27896.58 | 6.59 | $a\ {}^9D_5^\circ - y\ {}^{11}F_4$ |
| 3582.01 | 25 | 200 | II A | 27909.35 | 9.35 | $a\ {}^9D_4^\circ - z\ {}^9G_5$ |
| 3580.90 | 10 | 150 | II A | 27918.00 | 8.05 | $a\ {}^9D_4^\circ - y\ {}^{11}F_5$ |
| 3576.35 | 3 | 150 | III A | 27953.52 | 3.58 | $a\ {}^9D_3^\circ -$ $32_4$ |
| 3548.98 | 12 | 100? | II A | 28169.09 | 9.17 | $a\ {}^9D_4^\circ -$ $48_5$ |
| 3537.510 | 25 | 250 | II A | 28260.42 | 0.44 | $a\ {}^9D_5^\circ -$ $38_4$ |
| 3534.030 | 25 | 200 | II A | 28288.25 | 8.29 | $a\ {}^9D_4^\circ - z\ {}^9G_6$ |
| 3525.147 | 60 | 300 | II A | 28359.53 | 9.57 | $a\ {}^9D_4^\circ -$ $42_4$ |
| 3522.20 | 4*d* | 6 | IV | 28383.26 | 3.37 | $a\ {}^7D_5^\circ -$ $77_5$ |
| 3513.654 | 300 | 1000 | I A | 28452.29 | 2.30 | $a\ {}^9D_5^\circ -$ $44_5$ |
| 3510.449 | 10 | 200 | III A | 28478.27 | 8.28 | $a\ {}^9D_5^\circ -$ $49_5$ |
| 3507.457 | 20 | 200 | III A | 28502.56 | 2.59 | $a\ {}^9D_5^\circ - z\ {}^9G_4$ |
| 3504.91 | 30 | 100 | V E<br>III A | 28523.27 | 3.27 | $a\ {}^9D_6^\circ - y\ {}^{11}D_5$ |
| 3501.661 | 5 | 15 | IV A | 28549.73 | 9.61 | $a\ {}^{11}F_5^\circ -$ $73_5$? |
| 3498.154 | 30 | 300 | II A | 28578.36 | 8.29 | $a\ {}^9D_3^\circ -$ $38_4$ |
| 3497.090 | 50 | 500 | II A | 28587.05 | 7.02 | $a\ {}^9D_4^\circ -$ $40_5$ |
| 3496.370 | 10 | 150 | III A | 28592.93 | 2.91 | $a\ {}^9D_4^\circ - z\ {}^9G_2$ |
| 3486.195 | 100 | 500 | III A<br>V E | 28676.39 | 6.27 | $a\ {}^9D_4^\circ -$ $41_4$ |
| 3472.883 | 50 | 200 | III A | 28786.31 | 6.36 | $a\ {}^9D_6^\circ - z\ {}^9G_7$ |
| 3472.37 | 1? | 8 | IV A | 28790.56 | 0.55 | $a\ {}^9D_3^\circ - z\ {}^9G_2$ |
| 3468.131 | ? | 150 | III A | 28825.75 | 5.70 | $a\ {}^9D_4^\circ -$ $42_4$ |
| 3462.23 | 1 | 15 | IV A | 28874.88 | 4.86 | $a\ {}^9D_5^\circ -$ $39_2$ |
| 3461.901 | 300† | 80 | III | 28877.62 | 7.58 | $a\ {}^9D_5^\circ - y\ {}^{11}D_4$ |
| 3460.52 | 1 | 20 | IV A | 28889.15 | 9.12 | $a\ {}^9D_5^\circ -$ $48_5$ |
| 3457.938 | 8*d*? | 150 | III A | 28910.72 | 0.76 | $a\ {}^9D_5^\circ - z\ {}^9G_2$ |
| 3457.54 | 1 | 5 | IV A | 28914.04 | 4.13 | $a\ {}^{11}F_6^\circ -$ $81_5$ |
| 3457.014 | 300 | 125 | III | 28918.44 | 8.43 | $a\ {}^9D_4^\circ -$ $44_5$ |
| 3455.271 | 100 | 500 | II A | 28933.04 | 3.02 | $a\ {}^9D_6^\circ - y\ {}^{11}D_5$ |
| 3452.42 | 8 | 10 | IV | 28956.92 | 6.90 | $a\ {}^7D_4^\circ -$ $79_4$ |
| 3451.009 | 5 | 60 | III A | 28968.76 | 8.72 | $a\ {}^9D_4^\circ - z\ {}^9G_4$ |
| 3449.11 | 30† | 20 | IV A | 28984.71 | 4.73 | $a\ {}^9D_5^\circ - z\ {}^9G_3$ |
| 3446.64 | 5 | 8 | IV | 29005.48 | 5.68 | $a\ {}^9D_2^\circ - z\ {}^9G_2$ |
| 3446.313 | 20 | 200 | II A | 29008.23 | 8.24 | $a\ {}^9D_5^\circ - z\ {}^9G_6$ |
| 3436.63 | 1 | 8 | IV A | 29089.96 | 9.99 | $a\ {}^9D_5^\circ -$ $39_2$ |
| 3435.982 | 12 | 100 | III A | 29095.45 | 5.43 | $a\ {}^9D_4^\circ - z\ {}^9G_5$ |
| 3435.643 | 5 | 40 | III A | 29098.32 | 8.35 | $a\ {}^9D_4^\circ - y\ {}^{11}D_3$ |
| 3432.394 | 3 | 25 | III A | 29125.87 | 5.89 | $a\ {}^9D_5^\circ - z\ {}^9G_2$ |
| 3430.311 | 10 | 200 | II A | 29143.55 | 3.55 | $a\ {}^9D_3^\circ -$ $42_4$ |
| 3429.746 | 4 | 30 | III A | 29148.35 | 8.38 | $a\ {}^9D_4^\circ -$ $45_2$ |
| 3427.124 | 5 | 12 | IV A | 29170.65 | 0.69 | $a\ {}^7D_5^\circ -$ $78_5$ |
| 3423.898 | 1500† | 400† | II | 29198.13 | 8.23 | $a\ {}^9D_5^\circ -$ $49_5$ |
| 3422.353 | ? | 150 | II | 29211.32 | 1.34 | $a\ {}^9D_5^\circ -$ $43_3$ |
| 3418.621 | 40? | 150 | II A | 29243.20 | 3.22 | $a\ {}^9D_6^\circ - y\ {}^{11}D_5$ |
| 3413.563 | 5 | 60 | III A | 29286.53 | 6.57 | $a\ {}^9D_5^\circ - z\ {}^9G_4$ |
| 3411.016 | 80 | 250 | II A | 29308.40 | 8.42 | $a\ {}^9D_5^\circ -$ $50_4$ |
| 3406.915 | 100 | 400 | II A | 20343.68 | 3.71 | $a\ {}^9D_4^\circ - y\ {}^{11}D_4$ |
| 3405.57 | 2 | 4 | IV A | 29355.27 | 5.25 | $a\ {}^9D_4^\circ -$ $48_5$ |
| 3398.516 | 20 | 80 | III A | 29416.20 | 6.20 | $a\ {}^9D_6^\circ - y\ {}^{11}D_5$ |
| 3398.304 | 8 | 8 | IV | 29418.03 | 8.04 | $a\ {}^7D_6^\circ -$ $81_6$ |

† Blend with Gd II line.

TABLE IX.—*Continued.*

| I A | King Intensity Arc | King Intensity Furnace | T C | Wave number Observed | Wave number Calc. | Desig. |
|---|---|---|---|---|---|---|
| 3397.324 | 60 | 250 | II A | 29426.52 | 6.47 | $a\ {}^9D_2^\circ - 43_2$ |
| 3397.220 | 80 | 300 | II A | 29427.42 | 7.45 | $a\ {}^9D_4^\circ - y\ {}^{11}D_7$ |
| 3392.743 | 20 | 100 | III A | 29466.25 | 6.23 | $a\ {}^9D_3^\circ - 45_2$ |
| 3388.614 | 50 | 200 | II A | 29502.15 | 2.15 | $a\ {}^9D_3^\circ - 46_2$ |
| 3375.135 | 2 | 12 | IV A | 29619.96 | 0.02 | $a\ {}^9D_2^\circ - 47_2$ |
| 3373.844 | 100 | 200 | II A | 29631.30 | 1.33 | $a\ {}^9D_2^\circ - y\ {}^{11}D_2$ |
| 3371.381 | 5 | 40 | II A | 29652.95 | 2.97 | $a\ {}^9D_3^\circ - y\ {}^{11}D_3$ |
| 3370.402 | 60 | 100 | II | 29661.56 | 1.56 | $a\ {}^9D_2^\circ - y\ {}^{11}D_4$ |
| 3364.98 | 1 | 10 | IV A | 29709.35 | 9.35 | $a\ {}^9D_4^\circ - y\ {}^{11}D_5$ |
| 3364.085 | 2 | 15 | IV A | 29717.26 | 7.28 | $a\ {}^9D_2^\circ - 46_2$ |
| 3361.724 | 60 | 150 | II A | 29738.13 | 8.16 | $a\ {}^9D_6^\circ - x\ {}^7D_5$ |
| 3357.612 | 100 | 250 | II A | 29774.55 | 4.55 | $a\ {}^9D_4^\circ - 50_4$ |
| 3350.788 | 10 | 80 | III A | 29835.18 | 5.15 | $a\ {}^9D_2^\circ - 47_2$ |
| 3325.842 | 25 | 60 | III A | 30058.96 | 8.96 | $a\ {}^9D_6^\circ - w\ {}^9F_5$ |
| 3323.987 | 10 | 25 | III A | 30075.73 | 5.74 | $a\ {}^9D_6^\circ - x\ {}^7F_6$ |
| 3322.144 | 20 | 80 | III A | 30092.42 | 2.40 | $a\ {}^9D_3^\circ - 50_4$ |
| 3317.254 | 200 | 600 | II A | 30136.77 | 6.75 | $a\ {}^9D_5^\circ - w\ {}^9F_4$ |
| 3312.553 | 8 | 25 | IV A | 30179.54 | 9.52 | $a\ {}^9D_5^\circ - 51_3$ |
| 3311.384 | 6 | 4 | IV | 30190.20 | 0.24 | $a\ {}^7D_4^\circ - 85_3$ |
| 3299.07 | 2 | — | V | 30302.88 | 2.95 | $a\ {}^7D_5^\circ - 84_{3,4}$ |
| 3294.080 | 200 | 500 | II A | 30348.78 | 8.72 | $a\ {}^9D_5^\circ - w\ {}^9F_3$ |
| 3291.484 | 200 | 600 | II A | 30372.71 | 2.76 | $a\ {}^9D_6^\circ - w\ {}^9F_6$ |
| 3289.105 | 10? | 30 | III A | 30394.68 | 4.65 | $a\ {}^9D_5^\circ - 51_3$ |
| 3282.254 | 200? | 400 | II A | 30458.12 | 8.11 | $a\ {}^9D_5^\circ - x\ {}^7D_5$ |
| 3279.918 | 250 | 500 | II A | 30479.82 | 9.81 | $a\ {}^9D_3^\circ - w\ {}^9F_2$ |
| 3277.516 | 80 | 100 | III | 30502.15 | 2.16 | $a\ {}^9D_6^\circ - 55_5$ |
| 3276.92 | 4 | 5 | III | 30507.70 | 7.68 | $a\ {}^9D_6^\circ - 56_5$ |
| 3271.750 | 200 | 400 | II A | 30555.91 | 5.90 | $a\ {}^9D_5^\circ - w\ {}^9F_1$ |
| 3267.643 | 200 | 300 | II | 30594.31 | 4.30 | $a\ {}^9D_5^\circ - 52_2$ |
| 3266.726 | 300 | 500 | II | 30602.90 | 2.88 | $a\ {}^9D_6^\circ - w\ {}^9F_4$ |
| 3259.940 | 200 | 250 | II | 30666.60 | 6.57 | $a\ {}^9D_3^\circ - w\ {}^9F_3$ |
| 3256.932 | 150 | 300 | II A | 30694.92 | 4.94 | $a\ {}^9D_5^\circ - w\ {}^9F_2$ |
| 3248.044 | 100 | 250 | II A | 30778.91 | 8.91 | $a\ {}^9D_6^\circ - w\ {}^9F_5$ |
| 3246.272 | 30 | 100 | III A | 30795.71 | 5.69 | $a\ {}^9D_6^\circ - x\ {}^7F_6$ |
| 3244.826 | 20 | 80 | III A | 30809.43 | 9.43 | $a\ {}^9D_2^\circ - 52_3$ |
| 3241.127 | 200 | 250 | II | 30844.59 | 4.56 | $a\ {}^9D_6^\circ - 60_5$ |
| 3240.727 | 40 | 40 | III | 30848.40 | 8.40 | $a\ {}^9D_6^\circ - x\ {}^7F_4$ |
| 3239.49 | 4 | 8 | III A | 30860.18 | 0.20 | $a\ {}^9D_5^\circ - x\ {}^7D_4$ |
| 3238.870 | 80 | 100 | II | 30866.09 | 6.10 | $a\ {}^9D_6^\circ - x\ {}^9D_5$ |
| 3237.234 | 80 | 150 | II A | 30881.69 | 1.70 | $a\ {}^9D_2^\circ - w\ {}^9F_3$ |
| 3233.145 | 100 | 200 | II A | 30920.74 | 0.73 | $a\ {}^9D_3^\circ - w\ {}^9F_4$ |
| 3232.779 | 80 | 200 | II A | 30924.24 | 4.24 | $a\ {}^9D_4^\circ - x\ {}^7D_5$ |
| 3223.785 | 2000? | 800 | I | 31010.51 | 0.51 | $a\ {}^9D_6^\circ - w\ {}^9F_7$ |
| 3222.670 | 50 | 60 | III | 31021.24 | 1.27 | $a\ {}^9D_5^\circ - x\ {}^7F_5$ |
| 3218.397 | 30 | 40 | III | 31062.43 | 2.44 | $a\ {}^9D_6^\circ - 54_4$ |
| 3215.260 | 1000 | 500 | I | 31092.73 | 2.71 | $a\ {}^9D_5^\circ - w\ {}^9F_6$ |
| 3203.413 | 50 | 80 | II | 31207.72 | 7.78 | $a\ {}^9D_5^\circ - x\ {}^9D_4$ |
| 3201.94 | 4 | 4 | III | 31222.07 | 2.11 | $a\ {}^9D_5^\circ - 55_5$ |
| 3201.366 | 4 | 8 | III A | 31227.67 | 7.63 | $a\ {}^9D_5^\circ - 56_5$ |
| 3199.585 | 150 | 100 | II | 31245.05 | 5.04 | $a\ {}^9D_4^\circ - w\ {}^9F_5$ |
| 3199.303 | 200 | 150 | II | 31247.81 | 7.82 | $a\ {}^9D_6^\circ - x\ {}^9D_6$ |
| 3192.486 | 3 | 5 | III | 31314.53 | 4.53 | $a\ {}^9D_4^\circ - x\ {}^7F_4$ |
| 3191.283 | 6 | 15 | III A | 31326.29 | 6.33 | $a\ {}^9D_6^\circ - x\ {}^7D_4$ |
| 3190.280 | 200 | 150 | I | 31336.18 | 6.17 | $a\ {}^9D_4^\circ - x\ {}^9D_3$ |
| 3177.03 | 4 | 6 | III | 31466.86 | 6.84 | $a\ {}^9D_6^\circ - x\ {}^7F_2$ |
| 3174.960 | 40 | 50 | II | 31487.38 | 7.40 | $a\ {}^9D_6^\circ - x\ {}^7F_5$ |
| 3170.81 | 3 | 5 | III | 31528.58 | 8.57 | $a\ {}^9D_4^\circ - 54_4$ |
| 3167.203 | 30 | 30 | II | 31564.50 | 4.51 | $a\ {}^9D_5^\circ - 60_5$ |
| 3165.046 | 25 | 30 | II | 31586.00 | 6.05 | $a\ {}^9D_5^\circ - x\ {}^9D_5$ |
| 3160.730 | 200† | 40 | II | 31629.14 | 9.18 | $a\ {}^9D_6^\circ - 63_5$ |
| 3160.410 | 15 | 20 | III | 31632.34 | 2.38 | $a\ {}^9D_5^\circ - x\ {}^7F_4$ |
| 3159.224 | 15? | 25 | III | 31644.21 | 4.18 | $a\ {}^9D_5^\circ - x\ {}^7D_4$ |
| 3158.629 | 125 | 100 | I | 31650.17 | 0.14 | $a\ {}^9D_4^\circ - x\ {}^9D_2$ |
| 3158.247 | 5 | 10 | III | 31654.00 | 4.02 | $a\ {}^9D_2^\circ - x\ {}^9D_2$ |
| 3156.274 | 8 | 12 | III | 31673.78 | 3.91 | $a\ {}^9D_4^\circ - x\ {}^9D_4$ |
| 3154.28 | 5 | 5 | III | 31693.81 | 3.76 | $a\ {}^9D_4^\circ - 56_5$ |
| 3149.770 | 15 | 20 | III | 31739.19 | 9.19 | $a\ {}^9D_4^\circ - 57_3$ |
| 3145.124 | 40 | 50 | II | 31786.07 | 6.07 | $a\ {}^9D_5^\circ - x\ {}^7P_4$ |
| 3139.166 | 30 | 30 | II | 31846.40 | 6.42 | $a\ {}^9D_2^\circ - 54_4$ |
| 3138.707 | 60 | 40 | II | 31851.06 | 1.10 | $a\ {}^9D_4^\circ - 58_2$ |
| 3137.303 | 125 | 80 | I | 31865.31 | 5.27 | $a\ {}^9D_2^\circ - x\ {}^9D_2$ |
| 3136.926 | 100 | 80 | I | 31869.14 | 9.15 | $a\ {}^9D_2^\circ - x\ {}^9D_3$ |
| 3135.151 | 30 | 40 | II | 31887.18 | 7.21 | $a\ {}^9D_5^\circ - 61_4$ |
| 3132.405 | 40 | 40 | II | 31915.13 | 5.18 | $a\ {}^9D_4^\circ - 59_3$ |
| 3130.513 | 3 | — | V | 31934.42 | 4.42 | $a\ {}^9D_5^\circ - x\ {}^7F_2$ |
| 3127.246 | 40 | 40 | II | 31967.78 | 7.77 | $a\ {}^9D_6^\circ - x\ {}^9D_5$ |
| 3124.905 | 40 | 60 | I | 31991.73 | 1.76 | $a\ {}^9D_5^\circ - x\ {}^9D_4$ |
| 3121.11 | 2 | 2 | III | 32030.63 | 0.64 | $a\ {}^9D_4^\circ - 60_5$ |
| 3119.013 | 60 | 50 | II | 32052.16 | 2.18 | $a\ {}^9D_4^\circ - x\ {}^9D_5$ |
| 3112.330 | 4 | 6 | III | 32120.98 | 0.95 | $a\ {}^9D_2^\circ - x\ {}^7D_2$ |
| 3111.187 | 80 | 60 | I | 32132.78 | 2.82 | $a\ {}^9D_4^\circ - 65_5$ |
| 3107.69 | 5 | 5 | III | 32168.94 | 8.95 | $a\ {}^9D_2^\circ - 58_2$ |
| 3101.608 | 20 | 20 | II | 32232.02 | 2.01 | $a\ {}^9D_5^\circ - 62_5$ |
| 3097.75 | 6 | 3 | III | 32272.16 | 2.17 | $a\ {}^9D_5^\circ - 57_3$ |
| 3091.63 | 3 | 4 | III | 32336.04 | 6.08 | $a\ {}^9D_5^\circ - x\ {}^7D_2$ |
| 3090.384 | 30 | 40 | II | 32349.07 | 9.13 | $a\ {}^9D_5^\circ - 63_5$ |
| 3087.049 | 40 | 40 | II | 32384.02 | 4.08 | $a\ {}^9D_5^\circ - 58_2$ |
| 3080.950 | 30 | 40 | II | 32448.12 | 8.16 | $a\ {}^9D_2^\circ - 59_2$ |
| 3069.517 | 8 | 5 | III | 32568.98 | 8.96 | $a\ {}^9D_5^\circ - 64_4$ |
| 3069.419 | 40 | 50 | I | 32570.02 | 0.05 | $a\ {}^9D_5^\circ - x\ {}^7P_4$ |
| 3059.916 | 100 | 40 | I | 32671.17 | 1.19 | $a\ {}^9D_5^\circ - 61_4$ |
| 3057.395 | 50 | 20 | II | 32698.10 | 8.14 | $a\ {}^9D_2^\circ - 62_5$ |
| 3046.482 | 125 | 60 | I | 32815.23 | 5.26 | $a\ {}^9D_4^\circ - 63_5$ |
| 3043.008 | 80 | 40 | I | 32852.69 | 2.77 | $a\ {}^9D_5^\circ - 65_5$ |
| 3026.207 | 20 | — | V | 33035.07 | 5.09 | $a\ {}^9D_4^\circ - 64_4$ |
| 3013.74 | 2 | — | V | 33171.73 | 1.69 | $a\ {}^9D_4^\circ - x\ {}^7P_3$ |
| 3009.418 | 20 | 10 | II | 33219.36 | 9.39 | $a\ {}^9D_6^\circ - 71_5$ |
| 2997.365 | 60 | — | V | 33352.94 | 2.94 | $a\ {}^9D_3^\circ - 64_4$ |
| 2990.45 | 40d | — | V | 33430.06 | 0.08 | $a\ {}^9D_6^\circ - 74_{5,6}$ |
| 2987.850 | 20 | — | V | 33459.15 | 9.17 | $a\ {}^9D_5^\circ - 66_4$ |
| 2982.554 | 100 | — | V | 33518.56 | 8.61 | $a\ {}^9D_6^\circ - 68_{4,5}$ |
| 2966.083 | 5 | — | V | 33704.68 | 4.67 | $a\ {}^9D_5^\circ - x\ {}^7P_3$ |
| 2954.404 | 10 | — | V | 33837.91 | 7.91 | $a\ {}^9D_5^\circ - 70_5$ |
| 2946.13 | 60 | — | V | 33932.94 | 2.99 | $a\ {}^9D_4^\circ - 67_3$ |
| 2945.574 | 250 | 6 | II | 33939.35 | 9.34 | $a\ {}^9D_5^\circ - 71_5$ |
| 2944.482 | 80 | — | V | 33951.93 | 1.94 | $a\ {}^9D_5^\circ - 72_{4,5}$ |
| 2941.635 | 100 | — | V | 33984.79 | 4.74 | $a\ {}^9D_4^\circ - 68_{4,5}$ |
| 2933.794 | 200 | — | V | 34075.62 | 5.65 | $a\ {}^9D_6^\circ - 76_5$ |
| 2927.398 | 150 | 10 | II | 34150.06 | 0.03 | $a\ {}^9D_5^\circ - 74_{5,6}$ |
| 2920.331 | 8 | — | V | 34232.70 | 2.70 | $a\ {}^9D_4^\circ - 69_3$ |
| 2919.440 | 25 | — | V | 34243.15 | 3.15 | $a\ {}^9D_5^\circ - 66_4$ |
| 2918.782 | 50 | — | V | 34250.86 | 0.84 | $a\ {}^9D_5^\circ - 67_3$ |
| 2914.252 | 60 | — | V | 34304.10 | 4.04 | $a\ {}^9D_4^\circ - 70_4$ |
| 2904.600 | 60 | 5? | III | 34418.09 | 8.07 | $a\ {}^9D_4^\circ - 72_{4,5}$ |
| 2903.752 | 200 | 10 | II | 34428.14 | 8.12 | $a\ {}^9D_6^\circ - 78_6$ |
| 2900.565 | 80 | — | V | 34465.97 | 5.97 | $a\ {}^9D_2^\circ - 67_3$ |
| 2899.032 | 125 | — | V | 34484.19 | 4.21 | $a\ {}^9D_6^\circ - 80_6$ |
| 2893.464 | 30 | — | V | 34550.55 | 0.55 | $a\ {}^9D_5^\circ - 69_3$ |
| 2892.084 | 300 | 10 | II | 34567.03 | 7.07 | $a\ {}^9D_4^\circ - 73_3$ |
| 2887.507 | 100 | — | V | 34621.82 | 1.89 | $a\ {}^9D_6^\circ - 70_4$ |
| 2875.558 | 15 | — | V | 34765.68 | 5.68 | $a\ {}^9D_2^\circ - 69_3$ |
| 2873.086 | 100 | — | V | 34795.59 | 5.60 | $a\ {}^9D_6^\circ - 76_5$ |
| 2848.16 | 8 | — | V | 35100.09 | 0.05 | $a\ {}^9D_2^\circ - 73_2$ |
| 2845.957 | 40 | — | V | 35127.26 | 7.25 | $a\ {}^9D_5^\circ - 75_2$ |
| 2844.265 | 15 | — | V | 35148.16 | 8.07 | $a\ {}^9D_6^\circ - 78_6$ |
| 2839.74 | 6 | — | V | 35204.16 | 4.16 | $a\ {}^9D_6^\circ - 80_6$ |
| 2835.104 | 50 | — | V | 35261.73 | 1.73 | $a\ {}^9D_4^\circ - 76_5$ |
| 2828.634 | 60 | — | V | 35342.38 | 2.38 | $a\ {}^9D_2^\circ - 75_2$ |
| 2824.394 | 40 | — | V | 35395.43 | 5.42 | $a\ {}^9D_6^\circ - 81_5$ |
| 2823.528 | 4 | — | V | 35406.29 | 6.18 | $a\ {}^9D_5^\circ - 82_{4,5}$ |
| 2811.293 | 60 | — | V | 35560.37 | 0.38 | $a\ {}^9D_6^\circ - 84_{5,6}$ |
| 2803.534 | 60 | — | V | 35658.78 | 8.82 | $a\ {}^9D_4^\circ - 79_4$ |
| 2799.818 | 20 | — | V | 35706.10 | 6.08 | $a\ {}^9D_6^\circ - 85_5$ |
| 2787.677 | 250 | — | V | 35861.61 | 1.55 | $a\ {}^9D_4^\circ - 81_5$ |
| 2786.854 | 100 | — | V | 35872.20 | 2.31 | $a\ {}^9D_6^\circ - 82_{4,5}$ |
| 2778.760 | 125 | — | V | 35976.68 | 6.67 | $a\ {}^9D_5^\circ - 79_4$ |
| 2775.100 | 80 | — | V | 36024.12 | 4.11 | $a\ {}^9D_4^\circ - 83_3$ |
| 2774.087 | 80 | — | V | 36037.28 | 7.32 | $a\ {}^9D_2^\circ - 77_2?$ |
| 2755.508 | 20 | — | V | 36280.25 | 0.33 | $a\ {}^9D_5^\circ - 84_{5,6}$ |
| 2744.477 | 25 | — | V | 36426.06 | 6.03 | $a\ {}^9D_6^\circ - 85_6$ |
| 2734.64 | 6 | — | V | 36557.08 | 7.09 | $a\ {}^9D_6^\circ - 83_3$ |

† Blend with Gd II line.

# An Extension of Toraldo's Theory of Phase Contrast. II*

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Some of the light intensity distributions calculated in the first paper of this series have been observed experimentally with the aid of a macroscopic set-up. Because of a peculiarity of the human eye, a degree of contrast which is far from optimum will be satisfactory for practical purposes.

The theoretical investigation begun in the first paper is continued. A measure of contrast is defined by analogy to Michelson's measure of visibility of fringes. An expression for this is derived for the case of a very narrow phase annulus filled with light except for a narrow zone along each edge.

The possibility of measuring the phase shift introduced by an object, with the aid of phase contrast equipment, is discussed.

SOME of the light intensity distributions calculated in the first paper of this series[1] were verified experimentally with a macroscopic set-up. Photographic objectives were used in place of the condenser and objective of the microscope. The phase pattern was a strip down the middle of the aperture. In this case, a good agreement between theory and experiment should still be possible even though the pinpoint of light in the back aperture is replaced with a line of light parallel to the edges of the phase strip. The latter arrangement was used because it made more light available for photography. The image formed by the objective was projected directly upon the photographic plate. Care was taken to adjust the exposure time so that the range of light intensities to be measured would fall within the linear portion of the characteristic curve of the photographic plate. The phase patterns and objects were made by evaporation in vacuum of fluorite and, for an absorbing layer, of inconel, upon plane parallel glass plates.

Figure 1 shows one of the resulting photo-micrographs together with the theoretical and experimental light intensity curves. The former is drawn out, the latter is dotted. The experimental curve was obtained from a microphotometer trace of a diapositive made from the photo-micrograph and was ratioed to give the best possible fit to the theoretical curve. Since the aperture of the instrument was wide compared to the phase strip, detail lying between the two metastable regions is not shown. For the purpose of these experiments, the metastable intensity is the limit approached by the intensity as $x \to 0$. Because of limitations of space, only one of these patterns is here reproduced.

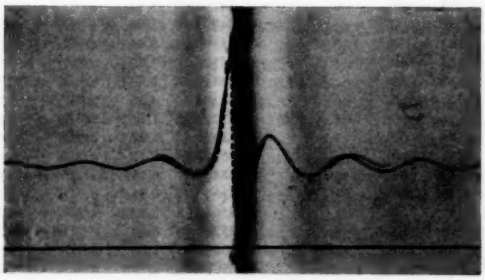

FIG. 1. Theoretical and experimental light intensity distributions. $(\alpha_1-q)/(s-q)=\frac{1}{2}$; $\varphi=+45°$; $\gamma=-66.°19$; $\tau=+0.7584$. Theoretical curve drawn out; experimental curve dotted.

Our results show, for the most part, a fair agreement between theory and experiment. Where the agreement is not so satisfactory it is safe to say that this is due to imperfections of workmanship, since the theory of diffraction has long been firmly established and is hardly open to any doubt. In every case, there is at least a qualitative agreement between the two curves. Unfortunately, the pressure of other business forced us to discontinue these experiments.

One surprising result of our experiments is that the subjective appearance of the light intensity distribution does not show any resemblance to what one would expect from the curves. The reason for this is a peculiar property of the human eye:[2] Where two areas of unequal brightness meet along a sharp line of discontinuity, the eye greatly exaggerates the contrast between the two; but if an area shows a continuous gradation of intensities, the eye greatly underestimates the intensity gradient. As a result, the light intensity distributions observed, of which Fig. 1 is a typical example, all present the same appearance: The edge of the object is bordered on one side by a black fringe, on the other side, by a bright fringe. Apart from these, there are other, insignificantly weak, fringes.

It is this peculiarity of the eye, rather than the rigorous theory given above, which jusifies the established practice of making the phase annulus much wider than the width recommended by the present theory, and of filling a considerable portion of it with light. The resultant gain in illumination is demanded by the practical microscopist, while the resultant deterioration of contrast will be largely compensated for by the tendency of the eye to exaggerate this contrast, provided that the width of the annulus is not excessive.

* For the notation, refer to the previous paper of this series (reference 1).

[1] L. I. Epstein, J. Opt. Soc. Am. 40, 291 (1950).

[2] B. O'Brien, H. S. Stewart, Jr., and C. J. Aronson, Astrophys. J. 89, 26 (1939).

Even if the annulus is very narrow, some deterioration of contrast below the metastable value is inevitable; for if the pinpoint of light in Fig. 1 in the previous paper[1] lies in the top or bottom part of the annulus, the line of light will cross the edge of the annulus in only two places, and the distance between these will not be negligible compared to the width of the aperture of the objective. This sacrifice of contrast is justified by the practical microscopist's demand for a phase pattern which is perfectly symmetrical in all directions.

The light intensity $|u_m|^2$ in the metastable region, as given by Eq. (7) of the previous paper,[1] is easily integrated with respect to $\alpha_1$ to take the effect of an extended light source into account. Only that case will be considered in which the illumination stops at the same distance from both edges of the phase annulus. Let

$$I=\int_{\frac{1}{2}(s+q)-k}^{\frac{1}{2}(s+q)+k}|u_m|^2 d\alpha_1, \tag{1}$$

and let $I_+$ be the value of $I$ for $x>0$, $I_-$ that for $x<0$. These quantities may be evaluated by integration of Eq. (7) of the previous paper. Let the measure of contrast $K$ be defined by analogy with the measure of visibility of fringes defined by A. A. Michelson:

$$K=(I_+-I_-)/(I_++I_-). \tag{2}$$

From Eqs. (7),[1] (1), and (2) it follows that

$$K=1/(C\csc 2\varphi+D\operatorname{ctn}2\varphi) \tag{3}$$

where

$$C=[\tau^2+1+(E/\pi^2)(1+\tau^2-2\tau\cos\gamma)]/2\tau\sin\gamma \tag{3a}$$

$$D=[\tau^2-1-(E/\pi^2)(1+\tau^2-2\tau\cos\gamma)]/2\tau\sin\gamma \tag{3b}$$

$$E=[(s-q)/2k]\int_0^{2k/(s-q)}\ln^2|(1+p)/(1-p)|\,dp \tag{3c}$$

$$p=[\alpha_1-\tfrac{1}{2}(s+q)]/\tfrac{1}{2}(s-q). \tag{3d}$$

The graph of $E$ against $2k/(s-q)$ is shown in Fig. 2. These values were obtained by numerical integration. The fact that the improper integral in Eq. (3c) converges when $2k/(s-q)\to 1$ is not to be regarded as proof that the present theory is still valid when the phase annulus is filled with light to its very edges. Even if a point of the light source is imaged onto the phase annulus without aberrations, this theory becomes invalid as soon as $\alpha_1$ approaches so close to either $q$ or $s$ that $|u|^2$ as derived from Eq. (3) of the previous paper differs significantly from $\tau^2$ even for values of $|x|$ which are not small compared to the radius of the field of view.

$|K|$ has a maximum when $\cos 2\varphi=-D/C$. Its value is given by

$$K_{\max}^2=1/(C^2-D^2)$$
$$=\sin^2\gamma/[1+(E/\pi^2)(1+\tau^2-2\tau\cos\gamma)]. \tag{4}$$

From Eq. (4), the following facts will be seen:

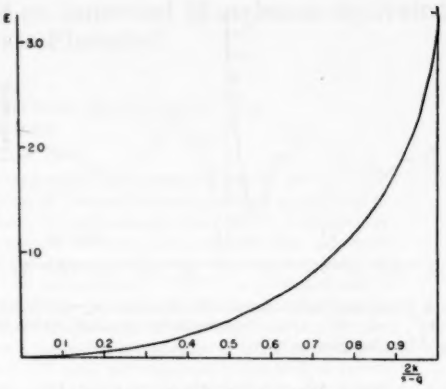


FIG. 2. Graph of $E$ against $2k/(s-q)$. Refer to Eqs. (3) through (3d).

Other things being equal, the greatest attainable contrast decreases as $\tau$ increases. This introduces no new difficulties, since a small transmission $\tau$ is desirable for thin objects (small $|\varphi|$).

Other things being equal, the greatest attainable contrast decreases as $E$ increases. If 80 percent of the phase annulus is filled with light ($2k/(s-q)=0.80$), the deterioration of contrast as compared to $E=0$ is not serious in those cases which are of practical importance. But as $2k/(s-q)$ increases from 0.80 to 1.00, $E$ is almost trebled.

If $E$ and $\tau$ are both small, the contrast will be greatest for any given value of $\varphi$ when $|\gamma|$ is close to $\frac{1}{2}\pi$, and the optimum value of $|\gamma|$ will differ from $\frac{1}{2}\pi$ by an amount which is small compared to the manufacturing tolerance. This defense of the customary quarter-wave annulus is more rigorous than that given in paper I.[1]

The present theory and the conclusions drawn from it are valid only for the case of a perfectly transparent object. The extension of this theory to partly absorbing objects is not likely to present any new mathematical difficulties. We have omitted it here because the usefulness of phase contrast equipment lies precisely in the fact that it introduces contrast into the image of a perfectly transparent object. Indeed, most thin biological objects in their natural state are practically perfectly transparent.

The extensions of the earlier theories of phase contrast to partly absorbing objects have already been

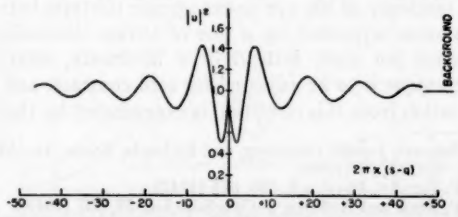


FIG. 3. Theoretical light intensity distribution. $(\alpha_1-q)/(s-q)=\frac{1}{2}$; $\varphi=-90°$; $\gamma=-90°$; $\tau=1$. This curve satisfies the condition for zero contrast, Eq. (5).

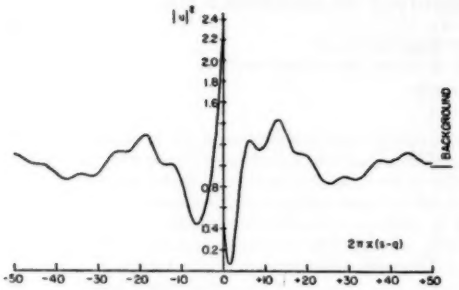


FIG. 4. Theoretical light intensity distribution. $(\alpha_1-q)/(s-q)=\frac{1}{3}$; $\varphi=-90°$; $\gamma=-90°$; $\tau=1$. Derived from the distribution shown in Fig. 3 by changing $\alpha_1$ only.

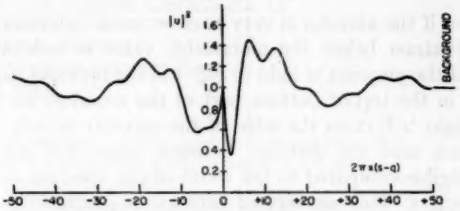


FIG. 5. Theoretical light intensity distribution. $(\alpha_1-q)/(s-q)=\frac{1}{3}$; $\varphi=+113.°81$; $\gamma=-90°$; $\tau=1$. This curve satisfies the condition for zero contrast, Eq. (5).

published. Thus, Bennett *et al*[3] have extended Zernike's[4] theory for a grating object; Keck and Brice[5] have extended Richter's[6] theory for a small object; and E. Menzel[7] has extended Françon's[8] theory for a strip object. These investigations show that the contrast in the image of such an object is sometimes increased when $\tau>1$ (annulus transparent, remainder of aperture absorbing) and $|\gamma|\neq\frac{1}{2}\pi$ (non-quarter-wave annulus).

If phase contrast equipment designed for a partly absorbing object is used for a perfectly transparent object, some diffraction phenomena will still be observed in general. While the contrast between the two metastable regions may be unsatisfactory under these conditions, the outer fringes will sometimes become pronounced and will then serve to emphasize certain object structures. Whether this is desirable in practice depends on the preference of the indivdual microscopist and on the object under examination.

The question is sometimes raised, whether phase contrast equipment can be used to measure the phase shift introduced by an object. It is argued that, for an object too thin to produce optimum contrast with a given phase pattern, contrast increases with increasing object thickness. If the eye could make a quantitative estimate of the measure of contrast $K$, the phase shift $2\varphi$ produced by the object could be calculated from this. However, it was proved conclusively by O'Brien et al[2] that this is not possible. To measure the intensity in either the bright or the dark metastable region, comparison between this and some standard intensity needs to be made; and this requires a double instrument and a comparison eyepiece. In such an instrument, the tendency of the eye to exaggerate contrast between two areas separated by a line of abrupt discontinuity becomes an asset instead of a hindrance, since the instrument is to be adjusted for zero contrast, and any deviation from this condition is exaggerated by the eye.

[3] Bennett, Jupnik, Osterberg, and Richards, Trans. Am. Microscop. Soc. 65, 99 (1946).
[4] F. Zernike, Physica 9, 686, 974 (1942).
[5] P. Keck and A. Brice, J. Opt. Soc. Am. 39, 507 (1949).
[6] R. Richter, Optik 2, 342 (1947).
[7] E. Menzel, Optik 5, 385 (1949).
[8] M. Françon, Rev. optique 25, 257 (1946).

This type of instrument will be greatly simplified if the variables $(\alpha_1-q)/(s-\alpha_1)$, $\tau$, and $\gamma$ are used to reduce the contrast between the two metastable regions to zero for a given value of $\varphi$, since then, the external intensity standard can be dispensed with. The condition for zero contrast is easily derived from Eq. (7) of the first paper, and is found to be

$$\ln|(\alpha_1-q)/(s-\alpha_1)|=\pi\,\mathrm{ctn}\varphi. \tag{5}$$

Since $\tau$ and $\gamma$ do not enter into this equation, laxity in manufacturing tolerances of the phase pattern will not impair the accuracy of this measurement. However, it is necessary that the conditions, under which Eq. (7) of the first paper is valid, be satisfied. This means that the phase pattern must be narrow compared to the total aperture, so that the use of a phase strip down the middle is indicated in preference to an annulus. It will be noted that this device can be used only when $|\varphi|$ is in the neighborhood of 90°, i.e. when the object introduces a phase shift of about half a wave-length. For as $|\varphi|$ begins to deviate from 90°, the value of $\alpha_1$ which satisfies Eq. (5), rapidly approaches either $q$ or $s$, i.e., for zero contrast, the pinpoint of light (or line of light parallel to the edges of the phase strip) must then be set so close to one edge of the phase strip that the theory of the method becomes invalid.

Our attempts to use this method on a biological object or a transparent crystal have not been successful. Some indication of the reason for this failure may be gathered from Figs. 3–5. When contrast is reduced to zero, some of the outer fringes may be more pronounced than the two metastable regions whose intensities are to be compared. In practical microscopy, these fringes lie close together and present a very confusing appearance. Moreover, the conditions underlying this theory are not likely to be accurately satisfied. This will be seen from the fact that an object of index 1.5, if placed in a medium of index 1.3, must have a thickness 3.75 times as great as the wave-length of light within the object to introduce a half-wave phase shift. The edge of such a thick layer is frequently rounded or slant. Even if it were perfectly square, it would sufficiently modify the wave front in its vicinity so that the form of the function $f(x)$ assumed in the derivation of Eq. (3) of the first paper would not be a good enough approximation.

# Temperature Dependence of the Emission of an Improved Manganese-Activated Magnesium Germanate Phosphor

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(Received May 25, 1950)

A number of recent researches have been concerned with magnesium germanate phosphors. An improved such phosphor is reported here having over twice the brightness of the previous compositions as prepared in this laboratory, and which shows peak luminescence efficiency at temperatures near 350°C. Temperature dependence of luminescence studies on the improved composition and the others showed little difference between them in this respect though the data are in striking contrast with those reported by others. A partial explanation of the pronounced temperature effect (for temperatures <350°C) is presented and is based upon the broadening of the excitation spectrum at elevated temperatures in such a way as to increase absorption of the exciting radiation (3650A). Data are presented showing differences in the temperature dependence relation effected by wave-length of excitation and method of measurement; in addition, curves are included showing the variation of phosphorescence ($t = 1/120$ sec.) with temperature as well as curves showing excitation and emission characteristics of the phosphor. Finally a practical application of this high temperature luminescence is demonstrated in the color corrected high pressure mercury lamps the emission characteristics of which are briefly discussed.

## INTRODUCTION

RED luminescing magnesium germanates activated with manganese are interesting phosphors both from theoretical and practical standpoints. They are of especial theoretical interest because of the unusual fine structure found in their luminescence emission spectra[1] (see Fig. 1); they are of practical interest because of their ability to function at unusually high temperatures under mercury ultraviolet excitation, thus providing for the first time really suitable phosphors for the color correction of high pressure mercury lamps.

Williams[2] was the first to report the fine structure in the emission of these phosphors though as far back as 1936 Leverenz[3] had prepared the meta- and ortho-magnesium germanates both of which, however, luminesce only very weakly under photo-excitation. The discovery by Williams[1,2,4] that a large excess of MgO above the ortho- proportions increased the photo-luminescence efficiency of the phosphor by a factor of about 5, served to place the material in the category of useful phosphors. He reported an optimum Mg/Ge ratio of 4 for 3650A excitation though a sample containing 10 MgO per $GeO_2$ still showed photo-luminescence efficiency as high as the original orthogermanate. In a later paper Patten and Williams[1] have reported on the temperature dependence of the luminescence of the "double-ortho" formulation and indicate that thermal quenching of luminescence begins in the neighborhood of 22–100°C with peak efficiency near 22°C. Other properties of the new phosphor as gathered from the literature[5] are that it is white in physical appearance and exhibits an exponential decay of phosphorescence.

It has been found possible in this laboratory to further improve the efficiency of the "double-ortho" magnesium germanate phosphor by replacing a portion of the MgO with $MgF_2$. Over-all luminous efficiency of the phosphor is approximately doubled by replacing 0.5 MgO with $MgF_2$ thus bringing the total improvement in brightness to 10 times that of the original ortho-germanate. The present paper describes the preparation of the new fluorogermanate samples, some of their properties with emphasis on the temperature dependence of luminescence, and finally a practical application of the high temperature red luminescence.

## PREPARATION OF THE SAMPLES

Both plain germanate and fluorogermanate samples were satisfactorily prepared using a dry mixing technique in which the required amounts of MgO, $MgF_2$, $MnCO_3$ (all C.P. Bakers "Analyzed") and $GeO_2$ (Eagle Picher, C.P.) were sieved through 100-mesh silk bolting cloth and ballmilled or ground thoroughly in a mortar before firing. However, the wet mixing method of

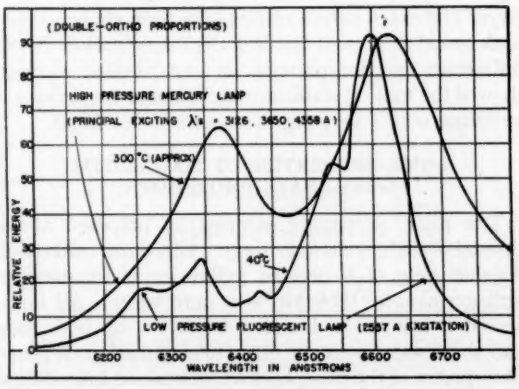


FIG. 1. Spectral distribution of the luminescence of magnesium fluorogermanate.

[1] S. H. Patten & F. E. Williams, J. Opt. Soc. Am. 39, 702 (1949).
[2] F. E. Williams, J. Opt. Soc. Am. 37, 302 (1947).
[3] H. W. Leverenz, U. S. Pat. 2,066,044 (1936).
[4] F. E. Williams, U. S. Pat. 2,447,448 (1948).
[5] H. W. Leverenz, *Luminescence of Solids* (John Wiley and Sons, Inc., New York, 1950).

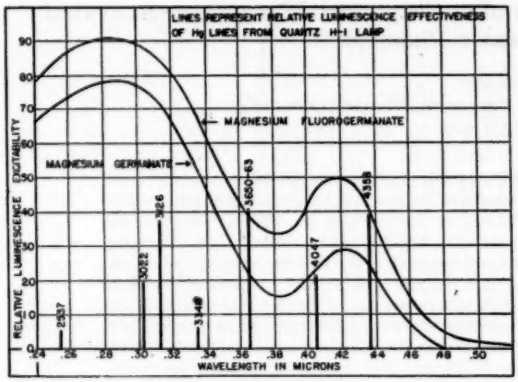
LINES REPRESENT RELATIVE LUMINESCENCE EFFECTIVENESS OF Hg LINES FROM QUARTZ H-I LAMP
MAGNESIUM FLUOROGERMANATE
MAGNESIUM GERMANATE
RELATIVE LUMINESCENCE EXCITABILITY
WAVELENGTH IN MICRONS

FIG. 2. Excitation spectrum of magnesium germanates (from reflectivity data).

Williams[2] in which a solution of soluble salts of the magnesium and manganese was used to form a slurry with $GeO_2$ which was then evaporated to dryness and ground preparatory to firing, was found somewhat superior for the plain germanates though not for the fluorogermanates. The samples reported here which contain no fluorine were prepared by the wet method and those containing fluorine by the dry method. Molar proportions used were 4 MgO; 1 $GeO_2$: 0.01 Mn for the plain germanates and 3.5 MgO; 0.5 $MgF_2$; 1 $GeO_2$: 0.01 Mn for the fluorogermanates. The intimately mixed and finely ground raw batches were fired in platinum containers in an electric wirewound alundum muffle furnace (air atmosphere) at temperatures between 1000–1200°C for about 30 min., after which they were again ballmilled (large batches) or ground in a mortar. For best results samples were then refired at about 1100°C for 30 min. to several days and then re-ground to pass 100 mesh bolting cloth. Samples of concern here were fired at 1080°C for 16 hours for this second firing. Firings in excess of about 2–3 hours produce a gradual improvement in brightness amounting to about 10–15 percent for times up to about three days. The exact nature of this long term change is not understood at present but is under investigation. X-ray diffraction powder patterns of the finished samples showed the well-crystallized magnesium orthogermanate structure with a very slight amount of free MgO.

## SOME PROPERTIES OF MAGNESIUM GERMANATE PHOSPHORS

The plain germanate samples as prepared above showed a slight yellowish tinge while those containing fluorine were of a decided yellow color (magnesium orthogermanate: 0.01 Mn is a pure white). All luminesced a brilliant red under excitation by both long and short wave mercury ultraviolet radiation. Absorption spectra of the phosphors were obtained from diffuse reflectance measurements made with the Beckman spectrophotometer and reflectance attachment using the tungsten and hydrogen sources and are plotted in Fig. 2 as representing excitation spectra. Absorption and excitation are apparently the same function of wave-length for these phosphors as will be seen later. The reason for the yellowish color of the samples is found in the pronounced absorption maximum (or reflection minimum) at about 4200A; another broader and more intense absorption band is maximum at about 2800A. These bands are definitely attributable to manganese as they are absent in samples identical in every other respect but containing no manganese.

Luminescence emission spectra were measured with an automatic recording spectroradiometer consisting

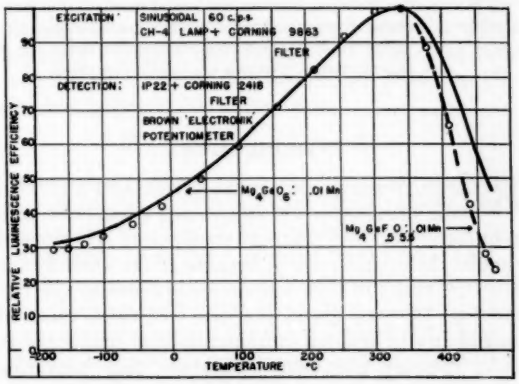
EXCITATION: SINUSOIDAL 60 c.p.s. CH-6 LAMP + CORNING 9863 FILTER
DETECTION: IP22 + CORNING 2418 FILTER BROWN 'ELECTRONIK' POTENTIOMETER
RELATIVE LUMINESCENCE EFFICIENCY
TEMPERATURE °C

FIG. 3. Temperature dependence of the luminescence of magnesium germanate phosphors.

essentially of a Beckman monochromator, cam corrected 1P22 photo-multiplier and cathode follower circuit feeding a Brown "Electronik" strip chart recorder having its chart drive synchronized with the prism drive of the monochromator. The spectral band width transmitted was about 50A at 7000A and about 30A at 6000A. Emission spectra of the phosphors appear to be the same for excitation by the mercury 2537, 3650, or 4358A lines and consist of a narrow band between 6000–6900A with five sharp peaks occurring at about 6260, 6340, 6425, 6535, and 6595A. These values are approximately 20–30A less than those obtained spectrographically by Williams[1] for the plain germanate; fluorine apparently has no effect on the wave-length position of the peaks. The effect of temperature on the emission spectrum is seen from Fig. 1 to be that of effectively smoothing out the weaker bands, broadening the two remaining, shifting them toward longer wave-lengths, and enhancing the shorter wave-length band relative to the longer. The highest peaks of the two spectra were equated in this figure so as to show more clearly the changes in distribution although the actual heights may not be far from equal, judging from the temperature dependence of the integrated spectral emission (Fig. 3). The luminosity of the luminescence spectrum is thus seen to increase with

increasing temperature and is due both to the spectral broadening and to the preferential growth of the band at 6340A.

As mentioned above, the red luminescence of magnesium germanate and fluorogermanate is excited by radiation absorbed within the bands shown in Fig. 2. For both 2537A and 3650A excitation the fluorogermanate has over twice the brightness of the unsubstituted samples as measured with a Weston Photronic cell with Viscor filter. Part of this increase may be attributed to the intensification of the absorption bands by the fluorine as illustrated in the figure. That the absorption and excitation are one and the same for photo-excitation of these phosphors in the wave-length range shown was confirmed experimentally by measuring the relative luminescence evoked by the individual lines of a high pressure mercury H-1 quartz lamp of fairly well-known energy distribution. The lines shown in Fig. 2 represent the relative amount of luminescence excited by the corresponding mercury lines from this lamp. When the values are divided by the phosphor absorption at each wave-length, the relative energy of each line is obtained thus demonstrating a luminescence efficiency which varies as the spectral absorption of exciting radiation. The actual quantum efficiency of the fluorogermanate was measured at

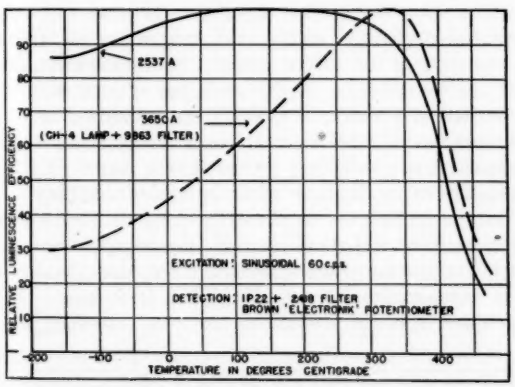


FIG. 4. Effect of exciting wave-length on the temperature dependence of the luminescence of magnesium fluorogermanate.

40°C and for 2537A excitation using the method of Thayer[6] and was found to be near 0.90; efficiency for 3650A excitation at 40° would probably be only half as great because of the decreased absorption.

## TEMPERATURE DEPENDENCE OF LUMINESCENCE MEASUREMENTS

Two general methods of obtaining the temperature dependence data were used. In one method the outputs of the photo-multiplier measuring the luminescence (1P21) and the one measuring ultraviolet intensity (1P28) were alternately presented on a cathode-ray screen and the two traces photographed on the same frame for the different temperatures of interest. The ultraviolet source was operated on a stabilized half-wave rectified 60-cycle supply so as to obtain more of the phosphorescence "tail" for future study (Fig. 8). Values plotted were the peak values of fluorescence *vs.* temperature. The other method differed only in that meters replaced the oscilloscope so that average values of luminescence and excitation intensity were measured instead of instantaneous peak values, and that the exciting source was operated on a full wave 60-cycle a.c. supply. In every case the phosphor to be measured was thinly coated on a rhodium or platinum surface the temperature of which could be varied from about −180°C to 450°C; samples were measured in vacuum (<1$\mu$ Hg). Temperatures were measured with an iron constantan thermocouple peened into a hole in the phosphor mounting block and either a Leeds and Northrup potentiometer or a Tagliabue Celect-Ray recorder-controller. Provision was made for isolating various spectral regions of the luminescence emission either by the use of appropriate filters or a large Hilger constant deviation spectrometer.

It is important in reporting temperature dependence of luminescence data that all pertinent factors be specified. Some of the factors found thus far that influence the type of relation obtained are (1) intensity of excitation (2) wave-length of excitation, (3) wave-length at which emission is measured, (4) impurities in the phosphor, and (5) technique of measurement (together with mode of excitation- pulsed or steady) e.g., whether instantaneous values of fluorescence or average values of luminescence are measured for pulsed excitation. The first factor appears important only in phosphors showing bimolecular phosphorescence decay[7] and is, therefore, of little concern here since magnesium germanate exhibits an exponential decay of phosphores-

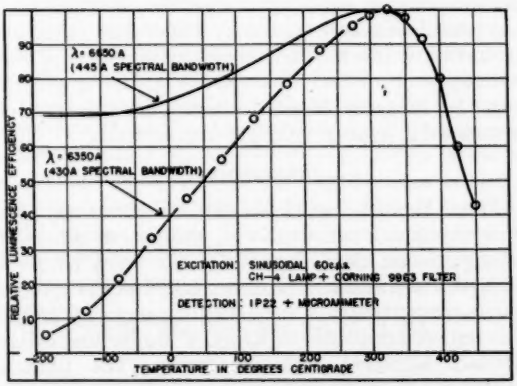


FIG. 5. Temperature dependence of the long and short wave-length emission of magnesium fluorogermanate.

[6] N. Thayer, Trans. Electrochem. Soc. 87, 424 (1945).

[7] G. R. Fonda and F. Seitz, editors, *Preparation and Characteristics of Solid Luminescent Materials* (John Wiley and Sons, Inc., New York, 1948) p. 112.

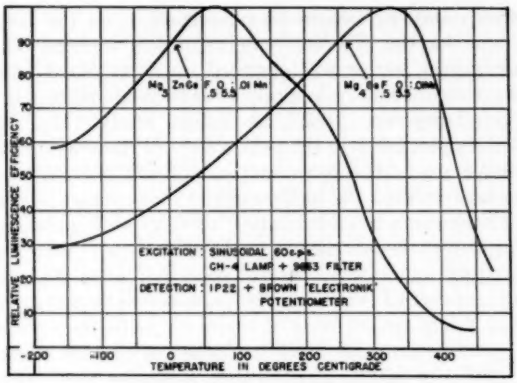
RELATIVE LUMINESCENCE EFFICIENCY
TEMPERATURE IN DEGREES CENTIGRADE
EXCITATION : SINUSOIDAL 60c.p.s. CH-4 LAMP + 9863 FILTER
DETECTION : IP22 + BROWN ELECTRONIC POTENTIOMETER

FIG. 6. Effect of zinc on the temperature dependence of the luminescence of magnesium fluorogermanate.

cence.[5] However, the intensity level was kept constant throughout these measurements for both long and short wave excitation.

Effects (2), (3), and (4) above are illustrated in Figs. 4–6 respectively, the curves of which were obtained by the second measuring technique described. Effect (4) is also shown in Fig. 3 for the case of fluorine substitution though it is not as pronounced as for the zinc substitution shown in Fig. 6. The different curves obtained for the same phosphor using the two measuring techniques are shown in Fig. 7 for 2537A excitation. The dotted curve in the lower-half of the figure represents the temperature dependence of the phosphorescence intensity 1/120 sec. after excitation has ceased (see Fig. 8); values are relative to the peak in the temperature *vs.* fluorescence curve. Just what is measured in the oscilloscope technique is clear from Fig. 8 which shows the cathode-ray traces obtained for the excitation and emission at two different temperatures of the phosphor. At the higher temperature the long term phosphorescence is almost completely quenched while the peak fluorescence is actually higher than at the low temperature. It is the variation in this fluorescence peak with temperature that is plotted in Fig. 7 along with the curve for the same phosphor obtained using the method of measuring average values of luminescence.

## DISCUSSION

From Figs. 1 and 2 magnesium germanate and fluorogermanate activated with manganese appear to belong to that class of phosphors in which both the excitation and emission processes take place in spectral bands characteristic of the activating impurity and in this respect are similar to Kroger's[8] magnesium orthotitanate activated with manganese. The titanate phosphor also shows fine structure in its luminescence emission and an excitation spectrum which correspond to those found in the germanates though in the titanate both excitation and emission are shifted slightly toward longer wave-lengths due probably to the effect of the host crystal. Kroger offers an abundance of evidence in favor of the existence of the manganese as $Mn^{4+}$ ions in the titanate and it would thus appear likely that the same is true for germanate phosphors rather than that it is in the divalent state as stated by Williams.[1] Oxidation effects for the germanates were somewhat similar to those reported for the titanates except that no green luminescence of the reduced samples was observed (see reference 5, p. 110). Since the transitions responsible for the absorption and emission processes in the $Mn^{4+}$ ion are associated with electrons in an incomplete inner shell shielded somewhat from external perturbations[5,8] one would expect the effects on these processes of thermal vibrations of the host lattice to be less than for $Mn^{2+}$ ions where the optical electrons are not shielded. That this is true for germanate phosphors is evidenced by the fine structure of the emission and perhaps to some extent by the relatively high efficiencies of these phosphors at elevated temperatures (compare, for example, $Mn^{2+}$ activated silicates).

If both the absorption and emission processes of the germanate phosphors are attributable to the Mn activator as suggested already, then one would expect that changes in the absorption spectrum with temperature similar to those for the emission spectrum (Fig. 1) might be observed. That the absorption does change is confirmed visually and by measurement of the diffuse reflectance of the 3650A (CH-4+9863 filter) excitation as the temperature of the phosphor is increased. At elevated temperatures (300°C) the phosphor is very noticeably yellower than at room temperature which means that absorption in the 4200A band (Fig. 2) becomes more intense with increasing temperature. Absorption (within the band peaking at 2800A) for the exciting radiation used in the temperature dependence measurements (3650A) more than doubles in the temperature interval 25–450°C. It is hoped that complete spectral absorption curves at elevated tem-

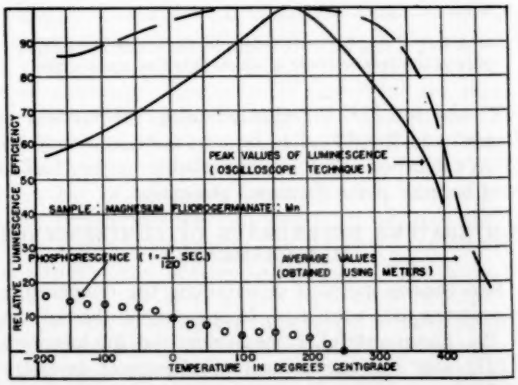
RELATIVE LUMINESCENCE EFFICIENCY
PEAK VALUES OF LUMINESCENCE (OSCILLOSCOPE TECHNIQUE)
SAMPLE : MAGNESIUM FLUOROGERMANATE : Mn
PHOSPHORESCENCE (1/120 SEC.)
AVERAGE VALUES (OBTAINED USING METERS)
TEMPERATURE IN DEGREES CENTIGRADE

FIG. 7. Temperature dependence of luminescence curves obtained using different measuring techniques. Excitation: 2537A.

[8] F. A. Kroger, *Some Aspects of the Luminescence of Solids* (Elsevier Publishing Company Inc., New York, 1948), p. 64.

peratures may be obtained soon. However, the present data are sufficient to account (at least partially) for the pronounced dependence of the 3650A excited luminescence upon temperature for temperatures below that at which the characteristic thermal quenching begins. From Fig. 4 it is seen that the luminescence is less temperature dependent for 2537A than for 3650A excitation for temperatures below the quenching point. This might be explained if the effect be attributed to a broadening and shift of the excitation spectrum and if the two exciting wave-lengths were located in such positions as to be affected differently by such a change. That they are is seen from Fig. 2; thus a broadening and/or a shift of the 2800A band toward longer wavelengths would affect absorption at 3650A much more than at 2537A which is near the peak of the band. Garlick and Gibson[9] have observed a similar effect with self-activated zinc sulfide phosphor.

The high temperature portion of the temperature dependence curves of the germanate phosphor shows the very rapid decay of luminescence with increasing temperature which is characteristic of most luminescent systems. Theoretical aspects of the phenomenon have been discussed by others[5, 7, 8, 10] but no satisfactory theory seems to have yet met with general acceptance and none is advanced here. Generally speaking, temperature dependence of luminescence data in the literature has been so lacking in specifications of experimental technique that it is hard to know just what has been measured and, therefore, harder still to understand how the theory could fit the data. Thus it would seem unsafe to attempt to fit the curves presented here with any relation derived from fundamental considerations without first correcting for the spectral selectivity of the filter-photo-tube combination used for detecting the changes which are plotted. Apparently the only temperature dependence data that would be of really unquestionable theoretical value would be that in which actual energy distributions of the luminescence are measured[1] for the various temperatures or that in which the total integrated luminescence is measured *vs.* temperature using an effectively non-selective receiver.

## A PRACTICAL APPLICATION OF THE HIGH TEMPERATURE LUMINESCENCE OF MAGNESIUM FLUOROGERMANATE

For a phosphor to be of practical advantage in the color correction of the well-known high pressure mercury lamps[11] it should possess the following characteristics: (1) It should be as white as possible so as not to subtract materially from the visible mercury emission. (2) It should respond efficiently to all wavelengths of the mercury ultraviolet generated in the high pressure arc. (3) It should possess (2) at elevated temperatures preferably near 400–500°C. (4) It should luminesce in the spectral ranges where mercury is deficient, i.e., primarily the red and (for complete color correction) also in the bluegreen, and (5) It should be thermally and photo-chemically stable at the temperatures and radiation densities encountered in the high pressure lamps. Magnesium fluorogermanate: Mn appears to be the first phosphor to fulfill all of these requirements in sufficient degree to warrant using it in such an application. A thin coating of this phosphor applied to the inside of the evacuated T-20 outer bulb of a 400 watt EH-1 lamp considerably improves the color rendering properties of the source with only a few percent over-all lumen loss. When the phosphor is coated on an outer bulb of optimal design an actual increase in efficiency of the lamps results in addition to the red correction which amounts to about 2600 total lumens radiated between 6000–7000A or 12 percent of the total visible radiation—approximately the same proportion of "red" as present in daylight! Thus there is made available a whole new series of efficient lamps of good color distribution for such applications as street lighting, technicolor and television studio set lighting, and high bay factory lighting to name but a few. A more complete specification of these lamps will be published elsewhere.

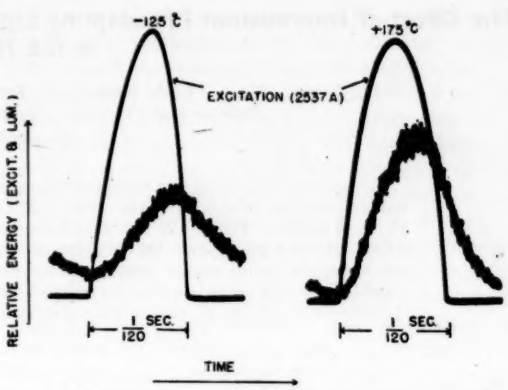


FIG. 8. Variation with time and temperature of the luminescence of magnesium fluorogermanate.

[9] G. F. J. Garlick and A. F. Gibson, Nature **161**, 359 (1948).
[10] F. E. Williams and Henry Eyring, J. Chem. Phys. **15**, 289 (1947).
[11] E. W. Beggs, Trans. Illum. Eng. Soc. **42** (4), 435.

# The Effect of Intermittent Preadapting Light upon Subsequent Dark Adaptation in the Human Eye*

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The influence of intermittent *versus* continuous preadaptation upon the dark adaptation of three subjects was measured for nine brightnesses (8860 to 22.15 ml) and four rates of interruption (2 cycles/second to 1 cycle/4 seconds). The data of the subjects were combined and the mean values used in the analysis of the results. The data are so nearly alike that it is considered there is no difference in subsequent dark adaptation which is related to the mode of preadaptation—for the durations of preadaptation used. No differences are found between any curve following intermittent preadaptation and its continuous control curve nor between the different curves for the various rates of interruption.

ONE of the variables affecting the extent and course of dark adaptation is the level of adaptation existing at the time measurements of the process begin. Many studies[1–6] have been carried out to determine the effects of varying the brightness and duration of the preadapting light upon the dark adaptation which follows. The aspects of dark adaptation which have been shown to be affected are: the initial threshold, the time elapsing before the shift from cone to rod adaptation, and the rapidity of rod adaptation. In all these studies the preadapting light was continuous and the durations varied from a few seconds (in one instance a photo-flash lamp was used) up to 40 minutes. In this experiment we investigated the effect of varying the brightness and rate of interruption of an intermittent preadapting light. We wished to know what effect discontinuous preadapting stimulation would have upon subsequent dark adaptation and whether there was any effect which could be attributed to differences in rate of interruption.

## APPARATUS AND PROCEDURE

The apparatus used both for preadaptation and threshold measurements was a monocular Hecht-Shlaer adaptometer. The instrument was mounted with the eyepiece projecting into a light tight cubicle within the laboratory so that the subject could be dark adapted regardless of the laboratory room lighting. Since the regular light source of the instrument was not suitable for our purpose, we removed it and substituted another. The light of a 500-watt, voltage regulated lamp was brought to a focus approximately 2 mm in diameter by condensing lenses and a microscope objective lens. A flicker disk with a 180° segment removed was located in the plane of this focus. Just beyond the disk a final lens cast the light beam so as to fill the stimulus opening of the instrument.

The adaptometer is so designed that the same light source serves both for preadaptation and threshold test measurement, and our substitute source preserved this feature. The brightness of the adapting stimuli was controlled by Wratten neutral tint fixed filters. A violet filter was used in conjunction with the neutral filters when threshold measurements were made, so that the subject could report on the presence or absence of color at threshold and so that there would be maximal rod contribution during dark adaptation. The threshold test flashes lasted 0.2 sec. and were presented by a pendulum shutter attached to the adaptometer. All preadaptation and threshold measurements were made through a 2-mm artificial pupil inserted into the eyepiece of the instrument. The preadapting stimuli were presented on the whole field of the instrument, an area of about 35° visual angle. The threshold test patch was 5°. The right eye was used, and the preadapting and test stimuli were centered 7° from the fovea on the nasal half of the retina. The flicker disk was rotated by a 1 r.p.s. synchronous clock motor and an arrangement of pulleys was used to vary the flicker rate.

Nine brightnesses were employed: 8860, 4430, 2215, 886, 443, 221.5, 88.6, 44.3, and 22.15 ml. The four flicker rates were 2 cycles/second, 1 cycle/second, 1 cycle/2 seconds, and 1 cycle/4 seconds. That is, to take 1 cycle/second as an example, in one cycle the light phase lasted ½ second and the dark phase ½ second.

Each session was conducted as follows: The subject entered the cubicle and was given a standard preliminary light adaptation-dark adaptation procedure. The stimulus was always 1772 ml. brightness, lasting for 1 minute, covering the 35° field of the instrument, and presented in the same position on the retina as the experimental and control stimuli. Threshold measurements were taken for 30 minutes. This preliminary was carried out for every subject at every experimental session, to insure, insofar as we could control it, that the level of dark adaptation at the time of starting the experimental procedure would be the same from session

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[6] C. P. Winsor and A.-B. Clark, Proc. Nat. Acad. Sci., Wash. **22**, 400 (1936).

to session, to allow the subject to stabilize his criterion of threshold visibility, to furnish data upon day-to-day variability, etc. At the expiration of this preliminary procedure the experimental intermittent preadaptation was started. The brightness for that session was set by inserting the necessary fixed filters into the apparatus, the rate of flicker was set by the correct pulley arrangement, the flicker motor was started, and the light turned on. At the end of 1 minute the motor was stopped and threshold measurements begun. At the end of the experimental procedure the control procedure was started. For the control the brightness was the same as for the experimental procedure, but it was uninterrupted and lasted for 30 seconds. Thus, as the control light was on for one-half the duration of the flickering experimental light, the total light-times-duration was the same for both procedures. At any brightness the series of experimental procedures consisted in going through all 4 flicker rates. For the higher brightnesses, 2215 ml and above, it was usually necessary to run a control for each individual experimental procedure; the time required to reach the final level of dark adaptation was so long that to attempt to combine more than one experimental procedure with a single control at a given session required too much time and fatigued the subject. In some sessions two or three experimental procedures and the single control were run, and for the lower brightnesses sometimes all 4 experimental procedures and the control were done in a single session. This varied from subject to subject and from brightness to brightness for each subject; no attempt was made to standardize this aspect of the experiment. The factor of brightness was standardized and the subjects proceeded through the experiment in the order from the highest brightness to the lowest; that is, for each subject all the data for 8860 ml were gathered before going to 4430 ml, and so on. The different flicker rates were used in random order.

The authors served as subjects and experimenters. Two, F. A. M. and A. J. R., furnished data for the whole brightness series. D. R. M. furnished data for 6 brightnesses: 8860, 4430, 2215, 443, 88.6, and 22.15 ml.

## RESULTS

In all, a total of 96 experimental and 54 control curves were obtained. In Figs. 1 and 2 are shown the plots of the averaged data for all 3 subjects for all brightnesses and flicker rates. The thresholds were recorded in log micromicrolambert units, and the values on the graphs are the arithmetic means of these logarithmic values. In the graphs the lines are drawn through the mean values for the control procedures; the symbols represent the values for the experimental points for the different flicker rates.

In the control data are found those aspects of dark adaptation which previous investigations have found to be the characteristic results of variations in preadaptation brightness. As the brightness increases the initial threshold increases; at the lowest preadaptation brightness this mean threshold is 4.80 log micromicrolamberts, at the highest it is 7.25. For brightnesses of 2215 ml and above the curves are divided into two portions and they show the discontinuity which is generally taken to represent the change-over from cone to rod adaptation. From the beginning of dark adaptation, the subjects reported on the color of the threshold stimulus until it was no longer present. The time of disappearance of color varied from subject to subject and, of course, from brightness to brightness for each subject. For those curves which show a discontinuity, it occurs earlier in the course of dark adaptation the lower the brightness of preadaptation. For 8860 ml it takes place after about 7 minutes, for 4430 ml after about 6, and for 2215 ml after only about 3 minutes. At the lower brightnesses colored early threshold stimuli were reported but the curves show no change in slope corresponding to the times when the change from colored to colorless stimuli occurs. At the three lowest brightnesses the initial thresholds appeared colored to F. A. M. and A. J. R.; for D. R. M. they did not. On all the curves, for the portion during which the threshold stimuli appeared

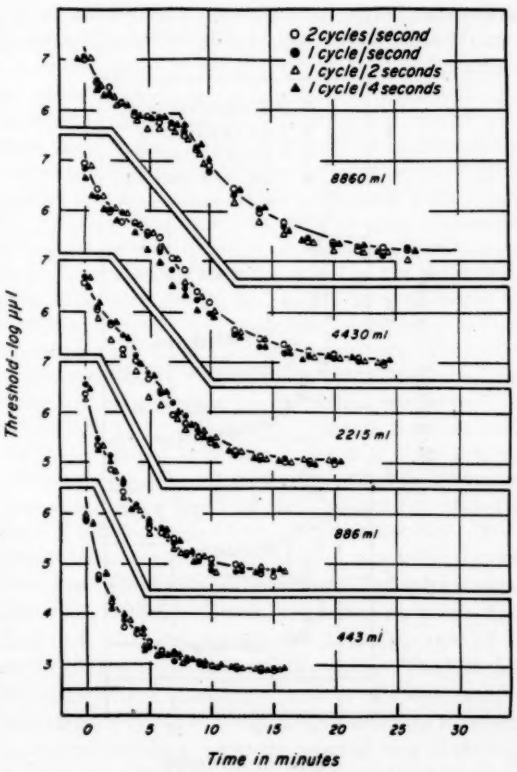



FIG. 1. Dark adaptation curves for the control and experimental procedures for preadaptation brightnesses of 443 ml and above. The lines are drawn through the values for the continuous control preadapting stimulation. The symbols represent the values obtained following the four rates of intermittent preadapting stimulation.

colorless, there is a relationship between preadapting brightness and the slope of the curve: the lower the brightness the steeper the slope.

With respect to dark adaptation after intermittent stimulation, the most prominent feature is the similarity of adaptation following this mode of preadaptation and that after continuous. As Figs. 1 and 2 show, at all levels of preadaptation the experimental values are very similar to the control values except for a possible tendency for some of the experimentals to be slightly lower than the controls for the three highest brightnesses. For all intents and purposes the experimental and control values for all flicker rates at a given brightness are about the same. Thus, the features of the control data—the initial threshold value, the time and value of the cone-rod discontinuity, and the slope of the rod portion of the curve—are paralleled in the experimental curves.

The range of flicker rates was 8 to 1, from 2 cycles/second to 1 cycle/4 seconds. We wished to find out if there was any variation or trend among the data which could be attributed to the factor of differences in rate. Although the initial threshold values and the extent of dark adaptation for the control and experimental curves were the same there might be differences in the slope of the rod portions from one experimental curve to another or between them and the controls which would be a function of the different rates of interruption. In order to obtain a clearer picture of slope differences we plotted the reciprocals of the mean threshold values for the experimental and control data for the colorless thresholds at 8860, 4430, and 2215 ml. The results are shown in Fig. 3. The lines have been drawn through the points by inspection. At each brightness the curve marked "*C*" is for the control data; the others for the four flicker rates are in order from left to right from most rapid to slowest. The difference in slope between the control and any experimental curve at a given brightness is slight; the same holds true for differences among the experimental curves, and there is no trend of slope which can be correlated with rate of flicker.

To conclude, in all their essential features, the experimental and control data are the same.

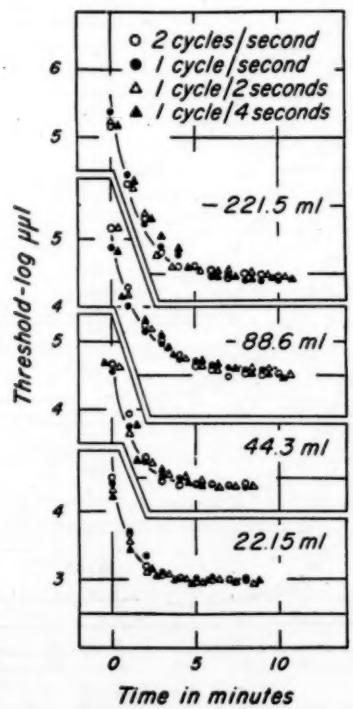



FIG. 2. Dark adaptation curves for the control and experimental procedures for preadaptation brightnesses of 221.5 ml and below. The lines are drawn through the values for the continuous control preadapting stimulation. The symbols represent the values obtained following the four rates of intermittent preadapting stimulation.

## DISCUSSION

We do not find reported any studies of dark adaptation where interrupted preadapting stimulation was used. In this exploratory experiment we sought to determine the effect of varying the rate of interruption for a wide range of preadaptation brightnesses—holding duration constant throughout. We wished to know what effect this mode of preadaptation would have upon the subsequent dark adaptation as compared with continuous preadaptation and also whether the data would furnish any information pertinent to Wald's schema of rhodopsin breakdown and regeneration.

Under the conditions of intermittent preadaptation there are two extreme situations: the preadapting flash brightness may be so low or the interval between flashes so long, or both, that there is complete recovery of sensitivity from the light-adapting effects of a flash before the next flash occurs. Then the net effect of the preadaptation would be nil; at the start and at the end of preadaptation the eye would be dark adapted and the thresholds would be the same at both times. The other extreme is the situation where the flash brightness, the length of the interval between flashes, or both, affect the visual system so that there is little recovery of sensitivity during the period from one flash to another. Then the course of dark adaptation would be nearly the same as for continuous preadaptation. Our results much more nearly fit the second situation than the first. For 886 ml preadapting brightness and all below it, the same curve of dark adaptation could be drawn through both the experimental and control points. At the three highest brightnesses the tendency for some of the experimental curves to be lower than the controls is not consistent; furthermore, it is not related to rate of flicker. In an investigation of the instrumental characteristics of the Hecht-Shlaer adaptometers they used, Hunt and Palmer[7] found that the discrepancy between duplicate

[7] E. Hunt and C. E. Palmer, Milbank Mem. Fund Quart. 18, 403 (1940).

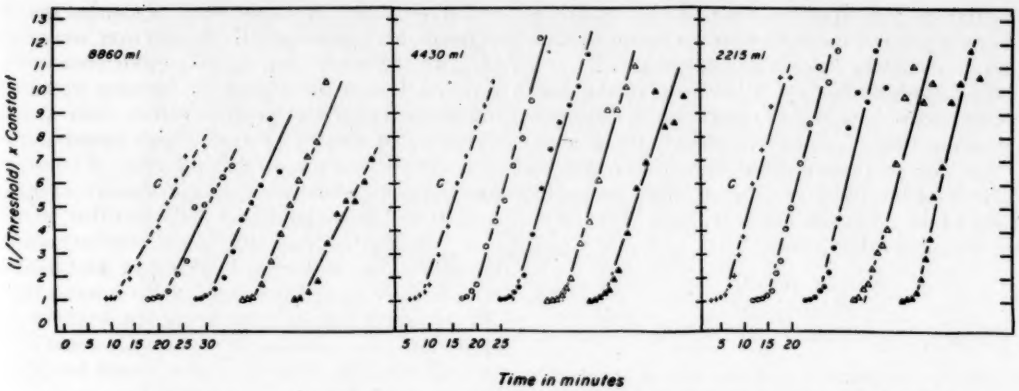



FIG. 3. Rectified dark adaptation curves for preadaptation brightnesses of 8860, 4430, and 2215 ml. In each panel, the curve marked "C" is for the continuous control procedure. The other four curves in each panel are for the experimental procedures: the four different rates of intermittent preadaptation. The symbols for the different rates have the same meaning as in Figs. 1 and 2. In each panel the abscissa values refer only to the control curve, the other curves have each been displaced to the right by a distance equal to ten minutes. The figure shows differences in slope for the different levels of preadaptation but little or no difference in slope at a given level.

readings on the same subject might be 0.5 to 1.0 log unit. The day-to-day variability in a single subject and the subject-to-subject variability in our experiment was of the same order of magnitude. Thus, the discrepancy between the experimental and control values at our highest brightnesses is probably a chance result.

In accounting for the effects of intermittent light upon the visual system according to his theory of the photo-chemical behavior of the retina, Hecht[8] assumes that a photo-sensitive material, $S$, is broken down under the influence of light into products $P$ and $A$. As soon as the $P$ and $A$ are formed they begin combining to regenerate $S$. A consideration of the reaction velocities of of the two processes leads to an equation describing an equilibrium between the two reactions—the photo-stationary state equation. When the light is intermittent, the additional factor of the regeneration reaction alone must be taken into account; during the dark phase of the light-dark cycle only this reaction goes on. Hecht combines the photo-stationary state and the regeneration ideas to derive expressions to account for flicker and the Talbot-Plateau phenomenon.

In discussing a photo-chemical explanation to account for brightness enhancement in flickering light, Jahn[9] points out that Hecht's equations describe the average quantity of photo-sensitive material at any given moment. If the flicker rate is high the actual quantity at any time will not vary much from the average. As the rate is decreased, however, the actual quantity tends to fluctuate with the same frequency as the flicker, and when the rate is low the magnitude of the fluctuations may be high. Under such conditions each flash begins when the quantity of photo-sensitive material is at a peak of the fluctuation, and the amount decomposed by each flash will be greater than that decomposed by the same quantity of steady light. In other words, at the time of each flash the eye will be more dark adapted than it would be in continuous illumination.

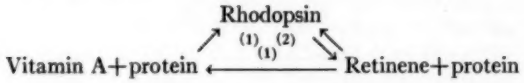
A consideration of the possibility that such a pattern of events might occur in intermittent light and that measurements of dark adaptation would furnish evidence upon it was one of the reasons we undertook the experiment. We argued that the net effect of interrupted preadaptation should be to leave the eye in a more dark adapted state than would be the case after stimulation with the same total quantity of continuous illumination. If this were the case then the extent of the subsequent dark adaptation should be less and its rate should be greater than under the continuous condition. It is clear that these expectations were not borne out by the results of the experiment, certainly not for the lower brightnesses and probably not for the higher ones as well.

The flickering mode of preadaptation is too untried, too few conditions have been explored, and our data are too meager for us to attempt to say much in the way of interpretation of light and dark adaptation upon the basis of information gathered in this experiment. With respect to the considerations brought forward in the preceding paragraphs our data indicate that there is practically no recovery of dark adaptation from one light flash to another and, further, that this is the case for all our brightnesses and rates of interruption. The fact that the intermittent stimulation was as effective in light adapting the eye as continuous light indicates some sort of summation effect. From the point of view of the way the interrupted light appeared to the subject, this was not summation of successive flashes. For none of the rates of interruption at any brightness did the light look continuous; at all times it was flickering light. From this standpoint the intermittent was clearly different from

[8] S. Hecht, Physiol. Rev. 17, 239 (1937).
[9] T. L. Jahn, Psychol. Rev. 51, 76 (1944).

the continuous preadaptation. From the standpoint of the effect of the two conditions upon subsequent dark adaptation there was little, if any, difference.

Another consideration which led us to conduct our experiment arose from Wald's conception of rhodopsin breakdown and regeneration. According to this scheme, rhodopsin may re-form directly from its breakdown products from the retinene stage or, more indirectly, from the vitamin A stage. The two modes of synthesis may be diagrammed as follows:




By varying the intensity and duration of preadaptation exposure, Wald and Clark[6] were able to change the course of rod adaptation. They predicted that following a short, intense flash of light dark adaptation would be rapid, reflecting the predominance of reaction (2). Prolonged pre-exposure should allow reaction (1) to predominate; hence dark adaptation should be relatively slow. In their experiment the early period of dark adaptation showed a rapid fall in threshold after short preexposure, a slower one after long.

We felt that the conditions of our experiment might allow these two modes of synthesis to make themselves apparent. Under the influence of continuous preadaptation reaction (1) would occur whereas reaction (2) would result from intermittent stimulation. Flickering light furnishes a situation where reaction (2) might be expected to be repeated time after time for the duration of the exposure period; consequently, dark adaptation should be rapid. Continuous preadaptation would allow opportunity for the system to be driven over into the Vitamin A stage, resulting in slower dark adaptation. However, the data do not show any difference in speed of dark adaptation which is related to the mode of preadaptation.

It may be too much to expect these patterns of the regeneration of rhodopsin to reveal themselves under the conditions of our experiment. For one thing, our duration of continuous pre-exposure (30 seconds) may have been too short for reaction (1) to get well under way, with the result that reaction (2) predominated. If this were so, then both conditions of preadaptation would result in regeneration following the mode of reaction (2) and no difference between the two conditions would be evident. A second possibility is that the effect of the flashes was to drive the system over into reaction (1) with the result that, again, no difference could be revealed. One of the reasons for choosing an extended brightness range and several, rather than a single, flicker rate was to try to cover a large enough compass of brightness and rate so that the effect of interrupted preadaptation would have an opportunity to appear. Against the second possibility is the fact that no difference between the intermittent and continuous conditions was found, although the extent of brightness and rates explored was great enough so that it seems reasonable to expect that at some brightness level for some flicker rate the conditions for reaction (2) would be met and the speed of dark adaptation would be different from another rate.

## SUMMARY

The course of dark adaptation for three subjects was measured following pre-exposure stimulation by intermittent and continuous light under conditions where the total light-times-duration was equal. Nine brightnesses were investigated, ranging from 8860 to 22.15 ml, and the range of the four rates of flicker of the intermittent stimulation was 8 to 1, from 2 cycles/second to 1 cycle/4 seconds. The measuring apparatus was a monocular Hecht-Shlaer adaptometer and the threshold values were recorded in log micromicrolamberts. The data of the three subjects were combined and the mean values used in the analysis of the results.

1. At any brightness the experimental and control data are so nearly the same that it is considered there is no difference in the subsequent dark adaptation whether the pre-exposure is intermittent or continuous—for the durations of stimulation used in this experiment.

2. No differences between any experimental and its control curve at a given brightness nor between the different experimental curves are found which are related to the rates of interruption of the intermittent preadaptation stimulation.

3. The results of the experiment are discussed in the light of Hecht's conception of the photo-chemical cycle of events which occurs in intermittent stimulation and in terms of Wald's hypothesis of the course of rhodopsin breakdown and regeneration.

# Loci of Constant Hue and Brightness Determined with Various Surrounding Colors*

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All colors which evoke the same hue and brightness are represented by a curve in the chromaticity diagram and have lower luminances for high saturations than for low. The various loci tend to converge on a point which represents an acceptable white under the conditions of adaptation produced by the surrounding color. The influence on adaptation of surrounding color beyond a ten-degree test field is of the same order of magnitude as the influence of the color of the comparison half of the test field.

AS long ago as 1910, Abney[1] reported that hue does not remain constant when highly chromatic light is diluted with white light. He noted a few exceptional hues, such as yellow and violet, which do remain unchanged upon dilution with white, but showed that desaturation appreciably shifts the hue of most other colors. The general character of this phenomenon is indicated by the constant hue loci derived from a study of the Munsell system by the OSA Subcommittee on Smoothing the Munsell System.[2]

In his theoretical analysis of colorimetry, Schrödinger[3] suggested that the series of colors involving the least number of just-noticeable steps between white and any saturated color should be a series of constant hue. Even now, thirty years after Schrödinger's suggestion, we do not have sufficiently complete and accurate data on the noticeability of color differences to justify confidence in any calculation of Schrödinger's "geodesic" paths of constant hue in the chromaticity diagram. Even if we had, for a test of his conjecture we should also need direct determinations of the paths of constant hue as judged by the same observers under precisely the same conditions as were used to obtain the data on color discrimination. It was, therefore, gratifying to discover that a new colorimeter, designed particularly to improve the accuracy of color discrimination data, is well adapted also for the determination of constant hue loci.

The optical principles of this instrument are shown in Fig. 1, which is a top view of the optical system. Light from the 1000-watt projection lamp, $P$, including much of that reflected by the concave mirror, $M$, is collimated by the molded plastic Fresnel lenses, $L_1$ and $L_2$. Each of these collimated beams passes through three (red, green, and blue) filters, $F$, which are each two inches wide and six inches high. The amount of light incident on each of these filters is regulated by thin metal diaphragms, $D$, which slide vertically so as to open or close to various extents the apertures of the collimating lens opposite each filter. The diaphragms are moved by lead screws having forty threads per inch. Those on the lens, $L_1$, are adjusted by simple hand knobs, and their positions are recorded to an accuracy of two and one-half thousandths of an inch (four hundredths of one percent of the full aperture) by direct-drive, star-wheel counters. The hand-operated diaphragms are set once only, at the beginning of every experiment.

The diaphragms on the lens, $L_2$, are driven by reversible electric motors, $A$, operated by remote control, as shown by the vertical view in Fig. 2. The lead screw and nut on one of the diaphragms is shown at $N$. The positions of these diaphragms are indicated by numbers, which are printed on a paper tape whenever the observer presses a button indicating that he is satisfied with the adjustments he has made by remote control. The shaft, $B$, transmits the position of the lead screw, $N$, to the printer. Returning to the top view, Fig. 1, we see that after passing over the diaphragms, $D$, and through the filters, $F$, the light is brought to a focus by Fresnel lenses, $L_3$ and $L_4$. Images of the filament of the projection lamp, $P$, are focused in one-inch square openings in two similar integrating spheres, $S_1$ and $S_2$. Diffuse reflections by the white interiors of those spheres thoroughly mix the beams from each of the two sets of filters. The baffles, $B$, prevent light from reaching the exit apertures, $L_5$ and $L_6$, unless it has undergone two or more reflections from the sphere walls. To this point each half of the colorimeter resembles the well-known Donaldson colorimeter. However, the remainder of the design is modified to permit binocular observation by an observer seated at any distance beyond two feet from the colorimeter, without any intervening optics or apertures. Fresnel lenses, $L_5$ and $L_6$, focus images of small portions, $W_1$ and $W_2$, of the sphere walls into

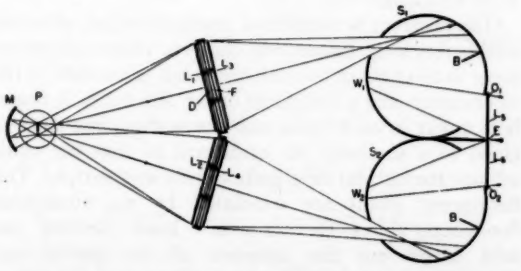


FIG. 1. Schematic diagram (top view) of wide-field binocular colorimeter showing twin optical systems and arrangement of integrating spheres to obtain contiguous fields.

* Communication No. 1346 from the Kodak Research Laboratories.

[1] W. de W. Abney, Proc. Roy. Soc. A83, 120 (1910).

[2] S. M. Newhall, D. Nickerson, and D. B. Judd, J. Opt. Soc. Am. 33, 385 (1943).

[3] E. Schrödinger, Ann. d. Physik (4) 63, 481 (1920).

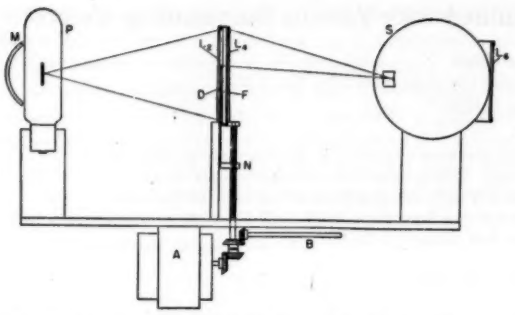


FIG. 2. Schematic diagram (side view) of colorimeter showing means of varying primaries and recording settings.

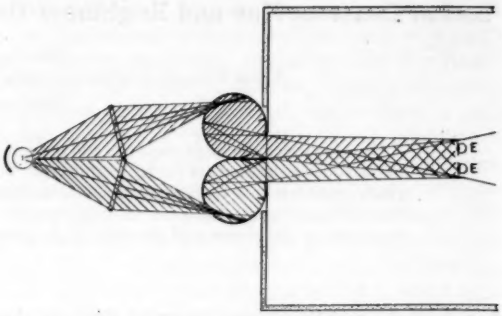


FIG. 3. Schematic diagram (top view) of observing booth and colorimeter showing size and overlapping of exit pupils.

coincident areas two feet in front of the colorimeter. This is accomplished by cutting the Fresnel lenses, $L_5$ and $L_6$, so that their optic centers are at $O_1$ and $O_2$. These lenses are each cut along a chord six inches long and three inches from the optic center. These two straight edges are placed together to form a photometric dividing edge at $E$. These coincident edges are used as the diameter of a circular mask which limits the photometric field to two adjacent semicircles with a vertical dividing edge.

Figure 3 shows that the observer may sit with both his eyes, $E$, within the large, coincident images of the sphere walls, $W_1$ and $W_2$, or at any distance beyond those images, on the center line. When he does so, he sees the lenses, $L_5$ and $L_6$, filled uniformly with light of color determined by the settings of the diaphragms, $D$. Since the two sets of filters are as nearly as possible identical, the colors of $L_5$ and $L_6$ are very nearly matched when the settings of the corresponding diaphragms are equal. When the diaphragms are adjusted to obtain an excellent color match, the spectral distributions of the energy from $L_5$ and $L_6$ are also very precisely the same. The luminance and chromaticity of the portions of the sphere walls, $W_1$ and $W_2$, are so uniform that there is considerable tolerance on head position. There is no observable disturbance of color match by parallax, either between the two eyes or resulting from head movements of an observer seated in an ordinary chair without a head clamp or other artificial restraint.

The observer is seated in a booth three feet wide and twelve feet long. Fluorescent cloths of various colors are hung so as to cover the wall surrounding the field of the colorimeter, and a foot or so of the side walls. A round hole is cut in each cloth and the surrounding cloth is glued to a similarly cut cardboard so that the cloth adjoins the circular field quite closely and sharply. The fluorescent cloths are irradiated by an ultraviolet floodlamp, above the observer's head. Neither the field lenses nor the interiors of the spheres are fluorescent, so there is no contamination of the colors in the test field by the ultraviolet source. Some light from the portions of the fluorescent cloth covering the side walls is scattered into the sphere, but the luminance it produces in the test field is so low that its constant effect is negligible in determinations of color discrimination and hue loci. For preliminary tests, a thin, opaque cylindrical tube was placed around the test field. This shielded the lenses and spheres from the light from the fluorescent cloths. The results of all tests indicate that the use of this shield is unnecessary. It has been discarded because it produced a black separation between the test field and the surrounding color unless the observer kept his head centered exactly in front of the colorimeter.

The remote-control switches for the colorimeter are built into a shallow table at which the observer sits. These are telephone-type, double-throw, dead-center, toggle switches. Each returns itself to center when the observer releases the handle. The recording switch is a button set into the table top near the control switches.

When the surrounding luminance was zero, the results shown in Fig. 4 were obtained, with the author as observer. For each experiment, the right-hand side of the test field was set to some hue, at the maximum saturation possible with the filters used in the colorimeter. After matching this color and recording his adjustments, the observer reduced the saturation of the left side of the field by adding the nearly complementary primary. Then, while endeavoring to maintain equality of brightnesses of the two halves of the test field, he adjusted the hue of the left side until it seemed to be the same as that of the right. In the case of a yellow, for instance, the observer found by trial which switch caused the hue to change with least disturbance of the brightness match. He then manipulated that switch until the left side of the field seemed neither more orange nor more green than the more saturated right side. Frequently, after obtaining the best equivalence of hue, the observer was conscious of a difference in brightness. He then corrected the brightness match by operating the switch which varied brightness with least disturbance of hue. If this noticeably disturbed the hue equivalence, a slight readjustment by use of the first switch usually sufficed for a good determination of a color

equivalent to the comparison color in both hue and brightness, differing only in saturation.

Particular attention was devoted to maintaining equal brightnesses in the test and comparison halves of the field, in order to avoid confusion of the Abney dependence of hue on saturation with the Bezold-Brücke[4] dependence of hue on brightness. Typical luminances necessary to produce constant brightness along each constant hue locus are indicated by numbers printed near representative points on each locus. These numbers show the luminance, in foot-lamberts, of the colors judged by the observer to have the same hue and brightness as the highly saturated comparison color, shown by the extreme point on each locus. The comparison colors for the several hues did not have equal luminances, so luminance values shown on different loci do not correspond to equal brightness. In the range from 5 to 50 foot-lamberts, the relative values of luminance for any constant hue and brightness are nearly independent of luminance. The determinations of luminance necessary for constant brightness are reproducible within 10 or 15 percent.

The variations of luminance required for constant brightness when only saturation is changed are not errors caused by use of an incorrect luminosity curve. All of the values of chromaticity and luminance were calculated from the colorimeter settings by use of the laws of additive color mixture and the ICI specifications of the filter and source combinations used as primaries. Only the blue filter transmits energy in the wave-length region, from 380 mμ to 460 mμ, for which there is evidence that the ICI 1924 luminosity curve may be in error. According to that curve, the luminous transmittance of the blue filter for light of the quality used in the colorimeter is 0.00603. According to the revised luminosity curve proposed by Judd,[5] the transmittance of the blue filter is 0.00633, a change of only 5 percent. The observed 50 percent variation of luminance, 4.5 to 7 foot-lamberts, required for equality of brightness of the maximum and minimum saturations on the constant hue locus for blue, shown in Fig. 4, therefore cannot be attributed to the use of the standard ICI luminosity curve rather than the luminosity curve for the actual observer. Similarly, the even greater variation of luminance required for constant brightness along the constant hue locus for red cannot be due to the use of an inapplicable luminosity curve, since differences between normal observers are even less for the red end of the luminosity curve than for the blue.

It is easy to show that the law of additivity, which necessarily applies to luminance because of its definition, does not apply to brightness. When a white mixture was kept unchanged in the comparison half of the field, and the red component of an equally bright white mixture was reduced in intensity, the resulting color was a bluish-green, very obviously *brighter* than the white. By merely removing red light from a white mixture, a brighter color was produced. The luminance as well as the energy content was obviously decreased, because the luminous red component was removed without any compensating increase of the other components. In order to obtain the resulting saturated color with brightness just equal to the white, it was also necessary to reduce the intensity of the green primary. This anomaly in particular and others like it forced themselves on the attention of the observers during the determinations of the constant hue loci. It cannot be attributed to a confusion of saturation with brightness. The observers tried without success to convince themselves that the bluish-green was darker than the white. They found that interpretation of their sensations quite unacceptable, and after keeping their attention directed to the saturation, they still judged the bluish-green to be brighter than the white from which it was derived by elimination of the red component.

This effect is probably responsible for much of the difficulty for which heterochromatic photometry is notorious. A single observer should, according to these results, be expected to produce quite different luminosity curves depending on whether he uses the comparison-with-white method or the step-by-step method, in which the energies of neighboring spectrum colors are adjusted for equal brightness. The success of the ICI system in accounting for metameric colors seems to indicate that luminosities based on the step-by-step comparison of spectral colors are additive. The variation

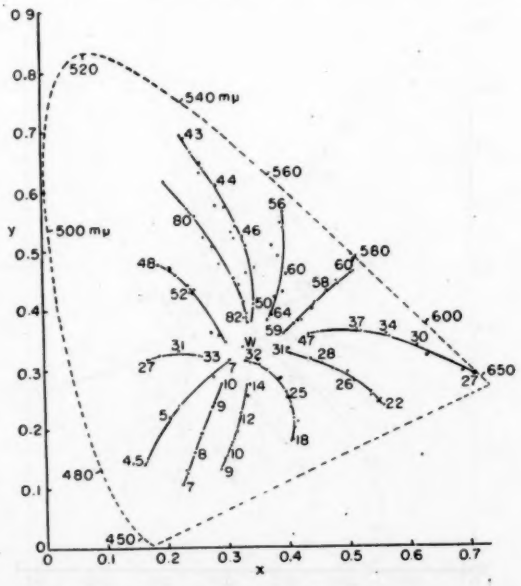


FIG. 4. Loci of constant hue for *DLM*, with dark surround and ten-degree field. Luminances (foot-lamberts) necessary for constant brightness for each hue are shown by numbers printed near typical points.

[4] W. von Bezold, Pogg. Ann. **150**, 221 (1873); E. Brücke, Sitzungsber. Akad. Wiss. (Wien) (3) **79**, 39 (1879).

[5] D. B. Judd, J. Opt. Soc. Am. **39**, 945 (1949).

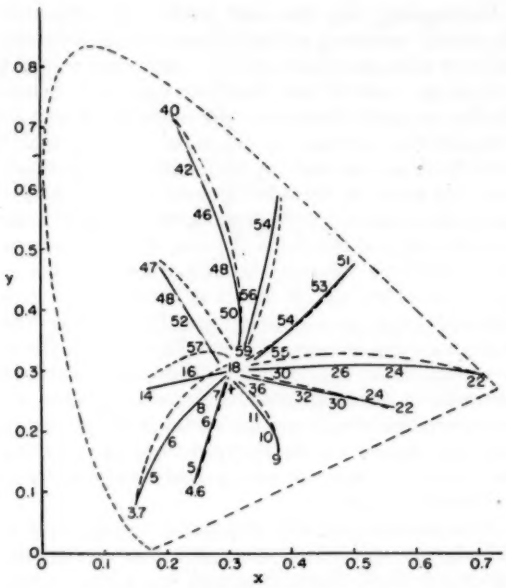

FIG. 5. Loci of constant hue for *DLM* (solid curves) and *WRJB* (broken curves) for nearly white surround (9 foot-lamberts) shown by cross. Luminances for constant brightness for each hue are shown numerically for *DLM*.

of luminance required for constant brightness when saturation is changed rules out the comparison-with-white method as a source of luminosity data which will follow an additivity law. The present investigation does not provide any evidence for answering the question whether flicker photometry can eliminate this effect and yield luminosity data suitable for use of the additivity law.

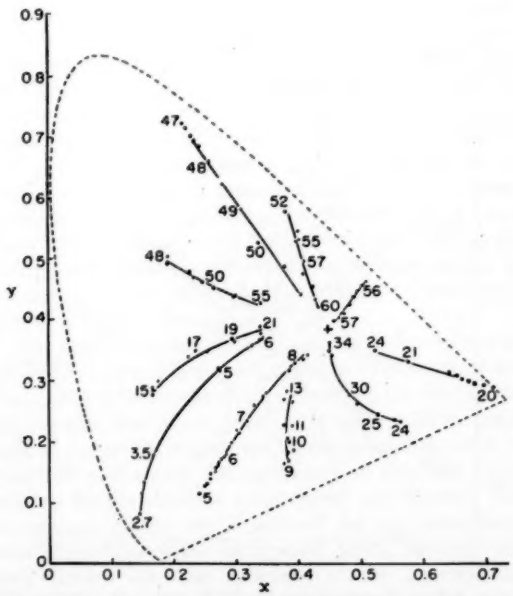

FIG. 6. Loci of constant hue for *DLM* for approximately tungsten-light surround (10 foot-lamberts) shown by cross. Luminances for constant brightness are shown numerically.

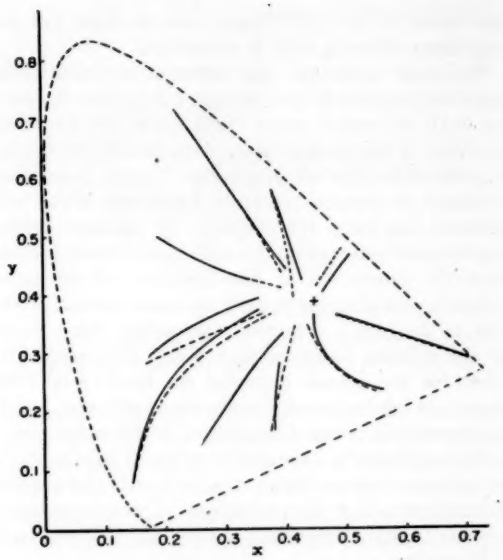

FIG. 7. Comparison of loci of constant hue for *DLM* (solid) and *WRJB* (broken), with approximately tungsten-light surround.

The saturation was decreased in successive trials until the left part of the field seemed white (or gray) and then the saturation was increased in successive trials until the comparison field was matched. Therefore, the points shown on the curves represent a double traverse of each constant hue locus. Most of the points represent single determinations, although a few represent the average of two or three settings. All of these determinations were made with a test field subtending ten degrees. Redetermination of a few of these loci with the observer ten feet from the colorimeter, when the field subtended only two degrees, resulted in substantially the same curves. Major hue changes were noticed as the observer moved from two to ten feet, but the loci of constant hue remained substantially unchanged for constant distance and subtense. The average point of convergence of all of the constant hue loci is represented by the point, *W*, which is also the point chosen as white in the darkroom when the right-hand side of the field is extinguished. The innermost point on each of the constant hue loci is the point judged to be white (or gray) when adjacent to the saturated comparison color. The comparison color is represented by the outermost point on each curve. This disturbance of the color judged to be white, caused by an adjacent highly chromatic color, is similar to that reported by Helson and Michels.[6]

Since no fluorescent cloth having the color of average daylight was available, an attempt was made to prepare

[6] H. Helson and W. S. Michels, J. Opt. Soc. Am. **38**, 1025 (1948).

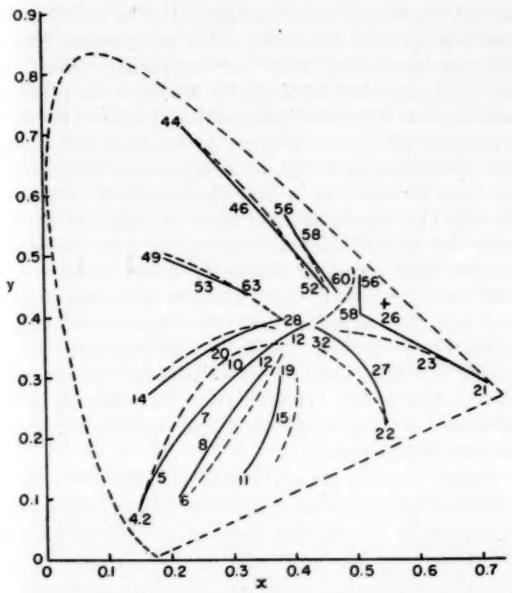


FIG. 8. Loci of constant hue for *DLM* (solid) and for *WRJB* (broken) for yellow surround (13 foot-lamberts) shown by cross. Luminances for constant brightness for each hue are shown numerically for *DLM*.

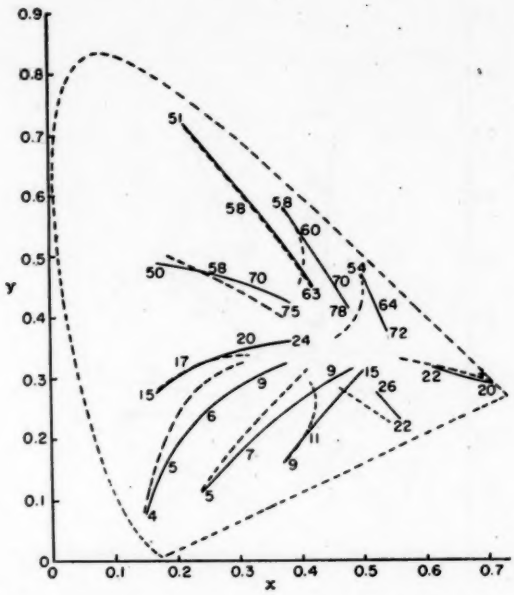


FIG. 9. Loci of constant hue for *DLM* (solid) and *WRJB* (broken) for red surround (5 foot-lamberts) shown by cross. Luminances for constant brightness for each hue are shown numerically for *DLM*.

such a background with available fluorescent water colors. The resulting color, shown by the cross in Fig. 5, was distinctly pink compared to daylight. The loci of constant hue obtained with this background are shown in Fig. 5. The solid curves are those obtained by the author and the broken curves are those obtained by W. R. J. Brown as observer. The differences are largely attributable to differences between the points of convergence for the two observers. This may be interpreted as a difference in degree of adaptation to the surround. The convergence points differ from that shown in Fig. 4 by being displaced almost along a straight line toward the point representing the color of the surround. This again is consistent with the findings of Helson and Michels.[6] The degree of adaptation, as indicated by the departure from the convergence point for black surround, is greater for the author than for Brown. The luminances required by the author for constant brightness for each hue are printed near each locus. Brown's data show even greater variations, all showing the same tendencies as the luminances noted on Fig. 5.

A fluorescent surround closely approximating the color of ICI standard source *A* was prepared. The constant hue loci found by the author with this surround are shown in Fig. 6, together with the experimental points and some representative values of luminance for constant brightness. A comparison of the curves obtained by the author and by Brown is shown in Fig. 7. Again, the degree of adaptation to the surround, being more complete for the author, seems to account for the major differences.

A yellow fluorescent cloth, when used as surround, produced the results shown in Fig. 8. Again, the author

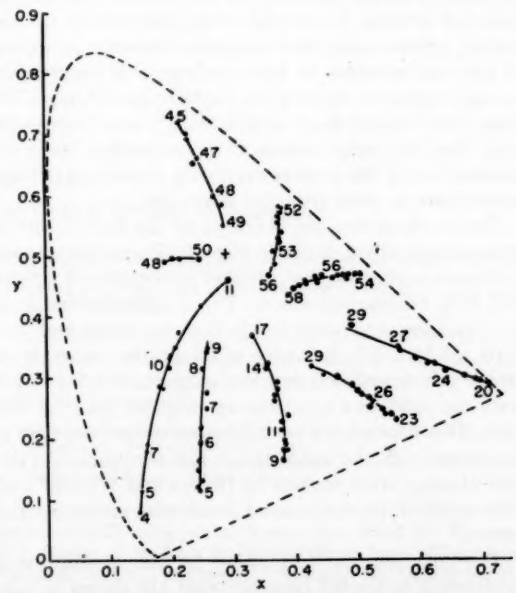


FIG. 10. Loci of constant hue for *DLM* for green surround (11 foot-lamberts) shown by cross. Luminances for constant brightness for each hue are shown numerically.

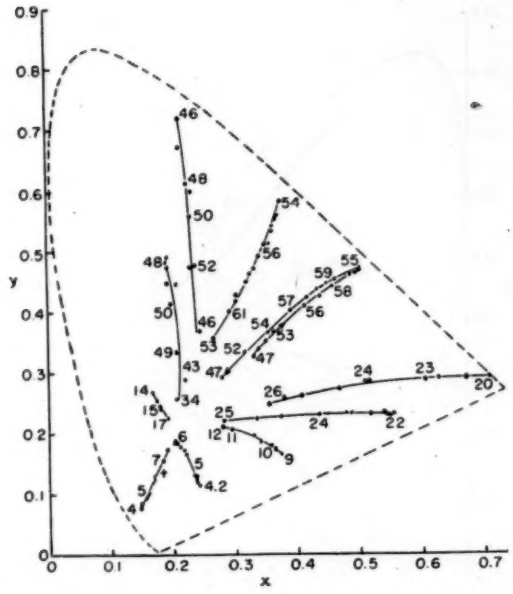


FIG. 11. Loci of constant hue for *DLM* for moderately saturated blue surround (7 foot-lamberts) shown by cross. Luminances for constant brightness for each hue are shown numerically.

seems to have been much more influenced by the surround.

A red fluorescent cloth produced the results shown in Fig. 9, in which again the major differences between observers seem to be accounted for by a greater degree of adaptation to the surround in the case of the author than for Brown. In several cases, particularly in the yellow, yellow-green, and magenta, Brown's condition of adaptation seems to have undergone a progressive change, reduction toward the daylight condition, as he progressed toward lower saturations. It is of interest to note that this effect seems to be reversible, since he followed much the same paths during the return to high saturations as when reducing saturation.

The constant hue loci obtained by the author with a green surround are shown in Fig. 10. There seems to be a difference between the points of convergence for light and dark comparison colors. The greatest influence of surround seems to occur for the blue and violet and perhaps red loci. The influence of adaptation seems least for the yellow, yellow-green, and magenta loci, for which tests the field was considerably brighter than for the blue. This dependence on brightness of the test field is consistent with the quantitative rule for predicting degree of adaptation devised by Helson and Michels[6] and later applied to the case of local adaptation by the author.[7]

The constant hue loci found by the author for a moderately saturated blue surround are shown in Fig. 11. In this case, the sequence of saturations was reversed, starting at what was judged to be white in the presence of each saturated color, progressing by increasing saturation until the comparison color was matched, and then returning by moderate decreases of saturation to a final redetermination of white. One complete path, out and in, is shown for constant yellow hue. The other hues gave even closer agreement between the out- and in-branches, so only the composite curves are shown. The degree of adaptation is indicated by the difference of the point of convergence from the result for the dark surround. Figure 12 shows constant hue loci found by Brown, using a highly saturated fluorescent blue cloth as background. The degree of adaptation appears to be negligible. This may be attributed partly to the low luminance (0.7 foot-lambert) of the blue surround, as well as to Brown's relative immunity to the influence of adaptation under the conditions of the present experiments.

Figure 13 shows the relations of all of the convergence points for the author relative to the colors of the various surrounds. In general, this is consistent with the findings of Helson and Michels,[6] and of the author,[7] for the effects of adaptation. However, the convergence points for the red and blue surrounds are more nearly on constant hue loci than on straight lines drawn to the points representing the surrounds from the "white" point or center of convergence for dark surround. The luminances (foot-lamberts) of the surrounding fields are printed near the crosses which represent their chromaticities.

All of the constant hue loci shown have been for a ten-degree field. It is reasonable to expect greater effects of adaptation with smaller test fields and further work

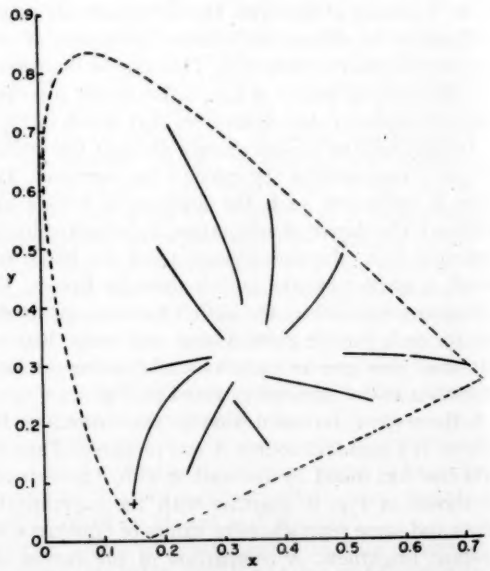


FIG. 12. Loci constant hue for *WRJB* for highly saturated blue surround (0.7 foot-lambert) as shown by cross.

[7] D. L. MacAdam, J. Opt. Soc. Am. 39, 454 (1949).

is planned to test that expectation. However, the effect of surround on adaptation with a ten-degree field seems to be greater than has been expected. Moon and Spencer,[8] particularly, have concluded that: "Foveal adaptation produced by a completely uniform field is caused largely by the portion of the field that is imaged on the fovea (1.5° diameter), the entire surround contributing less than ten percent of the total effect." In a case when they considered a change of color of surround corresponding to the entire range of Planckian radiators, they stated: "The effect of the surround on adaptation is again seen to be small, amounting to a few perceptible steps." Our results do not confirm this.

We may consider the distances between the convergence points and the first (white) point on each constant hue locus as indications of adaptation caused by immediately adjacent areas with their boundary centered on the fovea. We may take the displacements of the convergence points from the white chosen in a black surround as measures of the adaptation caused by the surround external to a ten-degree field. It is evident from all the results shown that, even for Brown, the effects of the surround external to a ten-degree field are of the same order of magnitude as adaptation produced by a stimulus imaged on the fovea.

Some practical consequences of this conclusion seem obvious. For instance, when color transparencies, still or motion pictures, are projected, appreciable distortions of hue will be produced by the surround if its chromaticity is appreciably different from that of a portion of the screen upon which the picture of a white object is focused, and if its luminance is greater than about ten percent of the luminance of the screen.

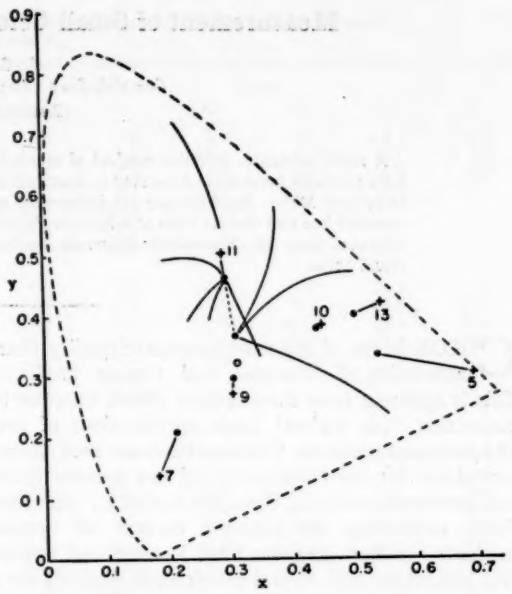


FIG. 13. Effects of adaptation caused by several surrounds (shown by crosses, luminances shown numerically in foot-lamberts). Solid points show approximate centers of convergence of constant hue loci for corresponding surround. Open circle shows "white" chosen in dark surround, and approximate center of convergence of constant hue loci for dark surround.

[8] P. Moon and D. E. Spencer, J. Opt. Soc. Am. **33**, 444 (1943).

## Thirty-Fifth Annual Meeting of the Optical Society of America

The thirty-fifth annual meeting of the Optical Society of America will be held at the Hotel Statler, Cleveland, Ohio, on October 26, 27, and 28, 1950. The program of this meeting will be mailed to members on October 7. In addition to contributed papers covering all phases of optics, special invited papers will include the following:

**"Growing Optical Crystals from the Fused Melt,"** H. C. Kremers, Harshaw Chemical Company.

**"Growing Large Barium Titanate Crystals,"** H. D. Williams, Harshaw Chemical Company.

**"The Properties of Large Barium Titanate Crystals,"** A. de Bretteville, Jr., Squire Signal Corps Engineering Laboratories.

**"Polarizer, Polarizing Beam Splitter, and Birefringent Elements; and Some Optical Systems in Which They Enter,"** C. D. West, Polaroid Corporation.

**"Some Experiences in the Production of Large Clear Crystals from Solutions,"** Bengt Kjellgren, Brush Development Company.

**"Optical Aspects of Piezoelectric Crystals,"** Hans Jaffe, Brush Development Company.

**"Reversibility and Irreversibility in Optics, or, Is Optics Possible,"** R. Clark Jones, Polaroid Corporation.

**"Michelson as a Man and as a Scientist,"** R. S. Shankland, Case Institute of Technology.

On Friday afternoon, October 27, the Society will be the guest of the General Electric Company at Nela Park. A tour of the Lighting Institute is being arranged, and the following invited papers will be presented:

**"Brightness Relationships for Comfortable Seeing,"** S. K. Guth, Lamp Department, General Electric Company.

**"Lamp Quality Optical Inspection Equipment,"** George Fabritius, Lamp Department, General Electric Company.

Arrangements are also being made for a trip to the Case Observatory on Thursday night, October 26, at which time Professor J. J. Nassau of the Case Institute of Technology, will speak on "Schmidt optics in astronomy." As usual, the Optical Society meeting will be open to non-members of the Society, and all interested persons are cordially invited to attend.

# Measurement of Small Color Differences in Tomato Purees

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*Campbell Soup Company, Riverton, New Jersey*
(Received June 7, 1950)

A rapid, accurate, objective method of measuring the small color differences of tomato purees has not been available heretofore. A method is described in which puree colors are measured with a Hunter Color-Difference Meter. Specifications are interpreted on a chromaticity diagram showing location of Munsell constant hue and chroma lines at a lightness level intermediate for most tomato purees. Appearance as interpreted from the chromaticity diagrams was in nearly perfect agreement with appearance scored on a visual basis.

COLOR is one of the most important quality characteristics of tomatoes and tomato products. This is apparent from the emphasis placed on color in connection with Federal grade specifications of raw and processed tomatoes. Visual methods are used almost exclusively for color evaluation of raw tomato fruits and processed products. Color evaluation by quantitatively estimating the pigment content of tomato products has been suggested by Kramer and Smith[1] and McCollum[2] and several colorimetric methods have been studied by MacGillivray[3] and Vogel.[4] While minimum colors for some Federal grades of processed tomatoes have been expressed in Munsell units, no system of specification has been commonly used to describe the colors of these products.

In connection with a tomato breeding investigation, an objective method of color description was needed which would accurately specify small color differences. A number of methods were used in preliminary studies but the method described herein, using the Color-Difference Meter described by Hunter,[5] was found to be the most applicable to the problem. The present study was concerned with the specification of tomato puree colors using the Color-Difference Meter and the correlation of these specifications with appearance.

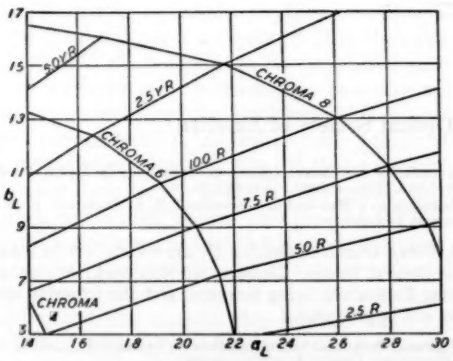


FIG. 1. Chromaticity diagram used to plot tomato puree colors. The *L* dimension, not illustrated in the figure, is entered numerically beside plotted points. Munsell renotation loci for hue and chroma were computed at 3/value as explained in text.

## METHODS

### Sample Preparation

All studies reported here involved puree colors. Tomato fruits were quartered, macerated and carefully heated to 80°C. Purees were prepared with either a Juice-X machine or a small, horizontal, paddle type extractor. Air introduced into the purees by the extractors was removed with a vacuum pump. The resultant product was free of skins and seeds, uniform in consistency and color, and included practically all of the color-bearing tissues and tomato liquids.

### Viewing Cells

Tomato purees are not perfectly opaque. A strong beam of light penetrates some distance into a puree and some of the light is scattered. A small-area illuminator was used with the Color-Difference Meter to concentrate the light beam on a small area, centrally located on the base of the viewing cell. The amount of puree in the viewing cells influenced instrument readings when depth of the purees was less than 2 cm. Instrument readings were not affected by covering the sides of viewing cells 6.5 cm in diameter with either white or black paper, thus indicating that loss of light laterally was not great. Accordingly, sample viewing cells were constructed of glass tubing having a 6.5 cm bore. Pieces of this tubing were cut in 4 cm lengths and optically clear glass was cemented to one end to form the base of the cell. Cells were filled within 0.5 cm of the top and the purees were viewed through the base.

### Color Standard

The Color-Difference Meter specifies colors most accurately when the circuits are initially balanced on a color similar to that of the specimen. A specially prepared, porcelain enamel standard, similar in color to tomato puree, was used. A reflectance curve with the specular component excluded was obtained for this standard using a G. E. recording spectrophotometer

[1] A. Kramer, and H. R. Smith, Food Res. 11, 14 (1946).
[2] J. P. McCollum, Am. Soc. Hort. Sci. Proc. 44, 398 (1944).
[3] J. H. MacGillivray, Am. Soc. Hort. Sci. Proc. 52, 415 (1948).
[4] A. C. Vogel, Plant Physiology 12, 929 (1937).
[5] R. S. Hunter, J. Opt. Soc. Am. 38, 661(A) (1948).

TABLE I. Munsell renotations for certain reds and yellow reds at values 2/, 3/, 4/ and 5/ in terms of Hunter's $L$, $a_L$ and $b_L$.

| Munsell V/C | $L$ | 5R $a_L$ | 5R $b_L$ | 7.5R $a_L$ | 7.5R $b_L$ | 10R $a_L$ | 10R $b_L$ | 2.5YR $a_L$ | 2.5YR $b_L$ | 5YR $a_L$ | 5YR $b_L$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/2 | 17.68 | 6.5 | 1.6 | 6.3 | 2.3 | 5.8 | 3.0 | 5.2 | 3.7 | 4.3 | 4.4 |
| 2/4 | | 12.6 | 2.8 | 12.2 | 4.1 | 11.5 | 5.5 | 10.4 | 6.7 | 8.5 | 7.9 |
| 2/6 | | 19.0 | 3.7 | 18.3 | 5.7 | 17.3 | 7.4 | 15.6 | 9.0 | 12.7 | 10.6 |
| 2/8 | | 27.0 | 4.7 | 25.7 | 7.0 | 24.4 | 9.1 | 21.8 | 11.2 | | |
| 2/10 | | 35.7 | 5.2 | 34.4 | 8.1 | 32.2 | 10.3 | | | | |
| 2/12 | | 45.0 | 5.6 | 43.7 | 8.9 | 41.4 | 11.2 | | | | |
| 2/14 | | 56.0 | 5.9 | 54.1 | 9.5 | 51.8 | 12.0 | | | | |
| 3/2 | 25.60 | 7.4 | 2.9 | 7.1 | 3.6 | 6.6 | 4.4 | 5.8 | 5.2 | 4.8 | 5.9 |
| 3/4 | | 14.6 | 5.3 | 13.9 | 6.6 | 12.9 | 7.8 | 11.1 | 9.1 | 9.0 | 10.1 |
| 3/6 | | 21.4 | 7.2 | 20.5 | 9.0 | 19.2 | 10.6 | 16.5 | 12.4 | 13.3 | 13.5 |
| 3/8 | | 29.5 | 9.0 | 28.0 | 11.2 | 26.1 | 13.0 | 21.5 | 14.9 | 16.9 | 16.0 |
| 3/10 | | 38.3 | 10.5 | 36.0 | 13.1 | 33.2 | 14.9 | 26.3 | 17.0 | | |
| 3/12 | | 47.8 | 11.6 | 45.1 | 14.5 | 41.2 | 16.5 | | | | |
| 3/14 | | 56.9 | 12.4 | 53.7 | 15.4 | 49.5 | 17.7 | | | | |
| 3/16 | | 67.2 | 13.2 | 63.7 | 16.3 | | | | | | |
| 4/2 | 34.64 | 7.2 | 3.1 | 7.0 | 3.8 | 6.6 | 4.8 | 5.9 | 5.9 | 5.0 | 6.9 |
| 4/4 | | 14.5 | 6.0 | 14.2 | 7.4 | 13.3 | 9.1 | 11.7 | 10.8 | 9.8 | 12.3 |
| 4/6 | | 21.8 | 8.5 | 21.1 | 10.4 | 19.5 | 12.7 | 17.0 | 14.7 | 13.9 | 16.3 |
| 4/8 | | 29.8 | 10.8 | 28.7 | 13.3 | 26.2 | 15.9 | 22.4 | 18.0 | 17.9 | 19.4 |
| 4/10 | | 37.6 | 12.7 | 36.0 | 15.6 | 32.9 | 18.5 | 27.2 | 20.7 | 21.4 | 21.9 |
| 4/12 | | 45.8 | 14.5 | 43.7 | 17.6 | 39.4 | 20.8 | 31.3 | 22.8 | 24.4 | 23.7 |
| 4/14 | | 55.4 | 16.1 | 52.1 | 19.4 | 46.0 | 22.6 | | | | |
| 4/16 | | 64.8 | 17.5 | 60.6 | 20.7 | 51.5 | 23.9 | | | | |
| 4/18 | | 75.2 | 18.6 | 69.8 | 21.9 | | | | | | |
| 4/20 | | 80.2 | 22.8 | | | | | | | | |
| 5/2 | 44.46 | 6.5 | 2.9 | 6.4 | 3.8 | 6.1 | 4.9 | 5.6 | 6.2 | 4.7 | 7.2 |
| 5/4 | | 14.4 | 6.2 | 13.9 | 7.9 | 12.8 | 10.0 | 11.3 | 11.7 | 9.3 | 13.5 |
| 5/6 | | 22.1 | 9.3 | 21.3 | 11.7 | 18.9 | 14.5 | 17.4 | 16.7 | 14.3 | 18.9 |
| 5/8 | | 30.3 | 12.0 | 29.1 | 15.2 | 26.8 | 18.5 | 23.5 | 21.0 | 19.0 | 23.1 |
| 5/10 | | 38.9 | 14.6 | 37.2 | 18.1 | 34.0 | 22.0 | 29.0 | 24.4 | 22.0 | 26.1 |
| 5/12 | | 48.2 | 16.8 | 45.8 | 20.8 | 41.0 | 24.9 | 33.5 | 27.0 | 26.1 | 28.3 |
| 5/14 | | 56.4 | 18.6 | 53.8 | 23.0 | 47.0 | 27.1 | 37.3 | 29.1 | 28.8 | 30.1 |
| 5/16 | | 66.4 | 20.4 | 62.8 | 25.0 | 53.2 | 28.9 | 40.2 | 30.6 | | |
| 5/18 | | 76.8 | 22.1 | 71.4 | 26.6 | 59.4 | 30.7 | | | | |
| 5/20 | | 86.3 | 23.2 | 79.8 | 27.9 | | | | | | |

fitted with black ports. I.C.I. tristimulus values were computed with a Librascope Tristimulus Integrator.* Tristimulus values ($X$, $Y$, $Z$) were converted to $L$, $a_L$ and $b_L$ using Hunter's formulas. These formulas are as follows:

$$L=100Y^{\frac{1}{2}},$$

$$a_L=\frac{175(1.02X-Y)}{Y^{\frac{1}{2}}},$$

$$b_L=\frac{70(Y-0.847Z)}{Y^{\frac{1}{2}}}.$$

It should be noted that Hunter's $L$, $a_L$ and $b_L$ are different from Hunter's $R_d$, $a$ and $b$ scales used by Nickerson.[6]

## Chromaticity Diagrams

Observations on a number of tomato purees indicated that lightness expressed in terms of $L$ varied from 22 to 28. Thus an $L$ of 25 was at an intermediate level. Fortunately, this value of $L$ is roughly equivalent to the Munsell value 3/ for which Munsell renotations in I.C.I. ($Y$, $x$, $y$) equivalents have been published by Newhall, Nickerson, and Judd.[7] Appropriate Munsell renotation loci in terms of $a_L$ and $b_L$ were plotted on

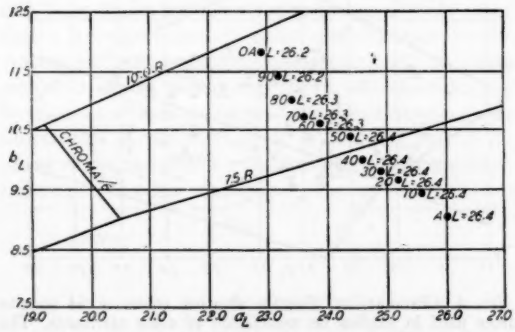


FIG. 2. Colors of tomato purees $A$ and $OA$ compared with mixtures of these purees containing 90, 80, 70, 60, 50, 40, 30, 20 and 10 percent puree $A$ with the balance puree $OA$. Hue differences between samples approximate the minimum that could be distinguished by most observers.

* The writer is indebted to I. H. Godlove and H. R. Davidson of the General Aniline and Film Corporation, Easton, Pennsylvania for their assistance in securing spectral reflectance curves and tristimulus values for the porcelain enamel standard.

[6] D. Nickerson, J. Opt. Soc. Am. 40, 85 (1950).

[7] S. M. Newhall, D. Nickerson, and D. B. Judd, J. Opt. Soc. Am. 33, 385 (1943).

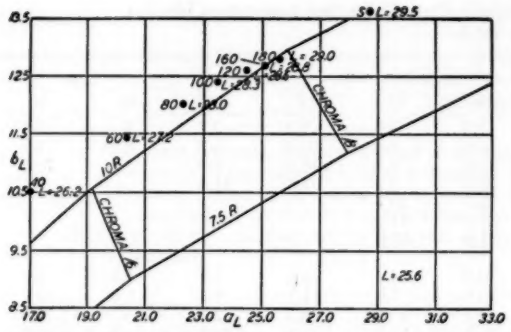


FIG. 3. Color of tomato solids (*S*) removed from a tomato puree by centrifugation in comparison with the color of water suspensions of the same solids. Suspensions contained 180, 160, 120, 100, 80, 60, and 40 percent of the centrifuged solids from the initial puree. Dilution markedly influenced chroma but changes in hue and lightness also occurred.

the Hunter type diagram at a lightness level equivalent to an L of 25.6 (Fig. 1). The colors of all tomato purees were plotted on this type of chromaticity diagram with lightness indicated numerically in terms of L. Munsell renotation loci in terms of $a_L$ and $b_L$ at Munsell values 2/, 3/, 4/, and 5/ are shown in Table I for certain reds and yellow reds commonly found in different tomato products.† With these data similar chromaticity diagrams may be constructed for these hues at three other levels of lightness.

### Visual Examination of Purees

All purees were examined visually in order to correlate location of colors on the chromaticity diagram with appearance. Visual examinations were made in daylight using purees contained in 130 ml square glass bottles. All samples were ranked in descending order with respect to appearance by persons experienced in evaluating tomato puree colors.

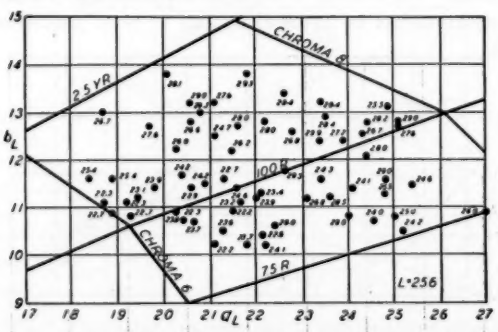


FIG. 4. Chromaticity diagram showing colors of 64 tomato purees used in studies on association of color attributes. The diagram also illustrates the range of tomato puree colors commonly encountered in a study involving several thousand samples.

† $L$, $a_L$ and $b_L$ were computed from I.C.I. tristimulus ($X$, $Y$, $Z$) data for the Munsell renotations given by Newhall, Nickerson, and Judd (see reference 7). The values of $X$ and $Z$ have not been published but tables giving both tristimulus and trichromatic ($x$, $y$) data are obtainable from Miss Nickerson.

### Reproduction of Color Specifications

Each day that the Color-Difference Meter was used, $L$, $a_L$ and $b_L$ readings were obtained for a red porcelain enamel panel. The color of this panel was substantially different from that of the standard used initially to adjust the instrument. $L$ readings obtained over a period of 5 months varied from 29.3 to 29.7, $a_L$ readings varied from 53.3 to 53.8 and $b_L$ readings varied from 17.4 to 17.8. In each case, readings varied about 0.2 of a unit above or below the mean readings, indicating that reproduction of color specifications over the period was good.

## RESULTS

### Perception of Hue Changes

The major color attribute influencing tomato puree appearance was hue. Most puree colors plotted on the chromaticity diagram with hues between Munsell 2.5*YR* and 7.5*R*. Purees were scored higher visually as the plotted points approached the redder hues. A few purees were examined for which plotted points fell near 6*R*. Such colors were regarded as highly acceptable. Purees with hues that were plotted near 2.5*YR* were unsatisfactory in appearance. A number of comparisons were made between purees alike in chroma and in value, but differing in hue, in order to determine minimum perceptible differences. One comparison is shown in Fig. 2. Purees *A* and *OA* were similar in lightness and chroma but different in hue. Puree *A* was mixed with puree *OA* so that resultant mixtures contained 90, 80, 70, 60, 50, 40, 30, 20 and 10 percent of puree *A*. A group of 12 persons scored puree *A* highest and *OA* poorest, while the mixtures were scored in the same order as enumerated above. From this and similar tests it was shown that a change in hue equal to 0.3 of a unit on the $a_L$ scale was readily distinguished by most observers. Hue changes were measured as differences in length of lines drawn perpendicularly from the nearest hue line to the points in question. For routine work, hue differences may be quickly determined with dividers.

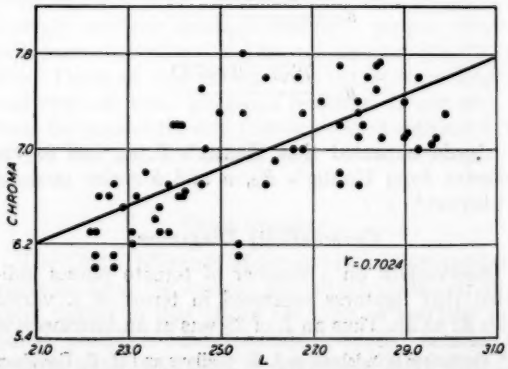


FIG. 5. Relationship of chroma and lightness attributes for 64 tomato purees. Chroma was estimated from the diagram in Fig. 4. The correlation coefficient ($r=0.7024$) was highly significant.

### Perception of Brightness Changes

The relationship between lightness and appearance of purees was less marked than between hue and appearance. In general, the darker purees were preferred. A number of purees had $L$ values of 22 and 23 and all such purees were scored as inferior to purees similar in hue but with a higher $L$. Purees identical in hue and in chroma, but differing widely in lightness, were rare. Numerous samples that varied from 0.5 to 2.0 $L$ units but which were similar in hue and in chroma were examined. With these purees, differences of one $L$ unit were readily detected. It was concluded that as $L$ declined, colors became more attractive but when $L$ was below 23, purees were less attractive than when $L$ was above 23.

### Perception of Chroma Changes

Fluctuations in chroma were noted between Munsell /5 and /8. Samples of similar lightness and hue but differing in chroma were not readily distinguished unless chroma differences were equivalent to approximately one-half of a chroma step. An association of light colors with high chromas and dark colors with low chromas made adequate sample selection difficult. Dilution of purees with water resulted in marked chroma changes. Solids from a tomato puree were concentrated with a centrifuge and the supernatant liquid discarded. Solids were then re-suspended in water so that resultant mixtures contained 180, 160, 120, 100, 80, 60 and 40 percent of the solids in the initial puree. Colors of the different mixtures have been plotted in Fig. 3. Dilution was associated with a marked reduction in chroma, a lowering of $L$ and a substantial change in hue at the higher dilutions. Changes in lightness were closely associated with changes in chroma.

### Interrelationships of Color Attributes

A group of 64 purees were selected representing most of the range of colors experienced in connection with color measurements on several thousand purees. For each puree, $L$, $a_L$ and $b_L$ readings were obtained. Chroma and hue values were determined by estimating the position of plotted points with respect to the position of constant hue and chroma lines on the chromaticity diagram. Correlation coefficients were determined between each of the color attributes. Position of the 64 puree colors on the chromaticity diagram are shown in Fig. 4. A highly significant correlation coefficient ($r=0.7024$) was noted between chroma and lightness of tomato purees (Fig. 5). The association of hue and lightness (Fig. 6) yielded a statistically significant correlation coefficient ($r=0.3529$) while hue and chroma values were not correlated. It was apparent from these data that hue was not closely related to the other attributes. A sufficiently large percentage of the lightness and chroma values were positively associated to suggest that the majority of the purees might be evaluated for appearance from only the hue and brightness attributes. But it was apparent that for precise classification of the 64 tomato purees, all color attributes needed to be considered.

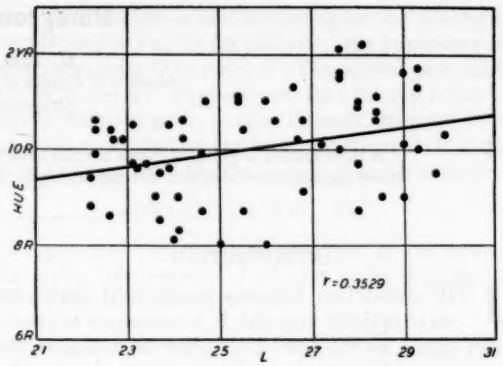


FIG. 6. Relationship of hue and lightness attributes for 64 tomato purees. Hue was estimated from the diagram in Fig. 4. The correlation coefficient ($r=0.3529$) was statistically significant.

### DISCUSSION

Over a period of 8 months color specifications have been obtained for several thousand tomato purees prepared at different locations, from different varieties, and from fruits harvested at different degrees of maturity. Interpretation of these specifications on chromaticity diagrams of the type described has yielded results in almost perfect agreement with those obtained by visual methods. In view of the speed, simplicity and objectivity of the method, it is believed that it may prove similarly useful for the specification of small color differences in other materials.

# Parageometrical Optics

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A third branch of optics is shown to exist between geometrical and wave optics. This intermediate link is called parageometrical optics. Several principles of geometrical optics can be suitably extended to it.

## INTRODUCTION

THE distinction between geometrical optics and wave optics is very old. It is customary to present wave optics as the true description of luminous phenomena and then to show that geometrical optics is a first approximation, holding for infinitely short wavelengths. Strictly speaking the distinction between the two fields is merely a quantitative one; but in practice the phenomenological differences are of a qualitative character. For this reason the division of optics into its two fundamental branches has not only a historical meaning, but still retains its validity nowadays.

During the last few years the existence of a third branch of optics has become more and more apparent. This branch is intermediate between geometrical optics and wave optics and presents well-defined qualitative features of its own. We call it *parageometrical optics* because its laws are simple generalizations of those of geometrical optics.

In geometrical optics the wave-length is assumed equal to zero; in parageometrical optics it will be very short, but not vanishingly small. Diffraction will take place according to Kirchhoff's assumption that the wave function in the apertures is the same as in free space. It is well known that this assumption is valid in almost every case one actually meets in instrumental optics.

## PARAGEOMETRICAL REFRACTION

We consider a plane screen with one or more apertures, which separates two homogeneous media of index of refraction $n$ and $n'$ respectively. To begin with, let the screen be a regular grating made out of parallel strips. We shall choose the three rectangular axes $x, y, z$ (unit vectors $\mathbf{i}, \mathbf{j}, \mathbf{k}$), so that $y$ is parallel to the strips and $z$ is perpendicular to the grating. A plane wave traveling in the direction $\mathbf{s}$, is incident from the medium $n(z<0)$. In the medium $n'$ we shall find a set of plane waves, diffracted in the directions $\mathbf{s}_p'$. If we denote with $\alpha, \beta, \gamma$ and $\alpha_p', \beta_p', \gamma_p'$ respectively the direction cosines of $\mathbf{s}$ and $\mathbf{s}_p'$, will hold the well-known relations there:

$$\begin{aligned} n'\alpha_p' &= n\alpha \mp p\lambda'/a, \\ n'\beta_p' &= n\beta, \end{aligned} \tag{1}$$

where $a$ is the period of the grating and $\lambda'$ the wave-length in the medium $n'$. These equations may be replaced by the following

$$n'\mathbf{s}_p' - n\mathbf{s} = N(s)\mathbf{k} + p(\lambda'/a)\mathbf{i}, \tag{2}$$

$N(\mathbf{s})$ being a scalar function of $\mathbf{s}$. For $p=0$ we obtain the ordinary law of refraction in the form given by Sommerfeld and Runge.[1] From (2) there follows also

$$(n'\mathbf{s}_p' - n\mathbf{s} - p(\lambda'/a)\mathbf{i}) \times \mathbf{k} = 0, \tag{3}$$

and again for $p=0$ we find another well-known form of Snell's law.[2]

We call Eq. (2) or (3) the law of *parageometrical refraction*. Assuming $n'=-n$, the law of *parageometrical reflection* is derived as a particular case.

In the case of a cross-grating, whose period is $a$ in the direction $\mathbf{i}$ and $b$ in the direction $\mathbf{j}$, the diffracted waves form a double set, and the law of parageometrical refraction takes the form

$$(n'\mathbf{s}_{pq}' - n\mathbf{s} - p(\lambda'/a)\mathbf{i} - q(\lambda'/b)\mathbf{j}) \times \mathbf{k} = 0. \tag{4}$$

A last generalization is necessary for an arbitrary screen of non-periodical structure, because in that case the double set of diffracted waves is no longer discrete, but continuous. Equation (4) must then be transformed into

$$(n'\mathbf{s}_d' - n\mathbf{s} - \mathbf{d}) \times \mathbf{k} = 0, \tag{5}$$

where $\mathbf{d}$ is a vector of the $x, y$ plane, which characterizes the diffracted wave considered. We shall say that Eq. (5) governs the parageometrical refraction of the $\mathbf{d}$-wave.

It can be shown by means of the Fourier transform[3] that the intensity of a $\mathbf{d}$-wave in Kirchhoff's approximation is independent of $\mathbf{s}$. Thus, a $\mathbf{d}$-wave has a well-defined individuality.

## THE THEOREM OF MALUS-DUPIN

Let us now inquire what happens when the incident wave is not a plane wave. In the case of ordinary refraction it is customary to decompose the incident wave into a great number of plane elements and to assume that each element is separately refracted according to Snell's law. After refraction it is possible for all the plane elements to unite again and thus to give rise to a single refracted wave. This possibility is secured by the theorem of Malus-Dupin, which states that from a normal congruence of rays, another normal congruence is obtained after refraction.

It is interesting to see that the same approach can be

[1] A. Sommerfeld and J. Runge, Ann. d. Physik, 35, 277 (1911).
[2] M. Herzberger, *Strahlenoptik* (J. Springer, Berlin, 1931), p. 10.
[3] G. Toraldo di Francia, Rend. Acc. Naz. Linc. 2, 787 (1947).

applied to a wave, generated by parageometrical refraction. To this end we consider a normal congruence $\mathbf{s}$, undergoing the transformation (5). A necessary and sufficient condition for the normality of $\mathbf{s}$ is $\mathbf{k}\cdot\text{curl}\,\mathbf{s}=0$. Taking then the divergence of both sides of (5) and remembering the vector identity $\text{div}(\mathbf{u}\times\mathbf{v})=\mathbf{v}\cdot\text{curl}\,\mathbf{u}-\mathbf{u}\cdot\text{curl}\,\mathbf{v}$, we see that

$$\mathbf{k}\cdot\text{curl}\,\mathbf{s}_d'=0. \tag{6}$$

Thus the diffracted congruence is still a normal congruence. This is the parageometrical generalization of the theorem of Malus-Dupin. It follows that we are allowed to speak of a **d**-wave, regardless of whether the incident wave is plane or not. As a consequence of this theorem, we note that a grating gives rise to a discrete set of diffracted waves, even when the incident wave has an arbitrary shape. In the case of an incident spherical wave, it has been possible to calculate the third-order aberrations of the **d**-waves.[4] Equation (5) represents the most general transformation that preserves the normality of line congruencies, being independent of the coordinates of the point of incidence.

Herzberger,[5] when reviewing the paper of reference 3, has pointed out that the vector $\mathbf{d}$ of Eq. (5), instead of being a constant, could be the gradient of an arbitrary function of $x$, $y$ (characteristic function). In fact it is easily seen that Eq. (6) would still be a consequence of Eq. (5). By this assumption we give up the independence of the transformation from the coordinates $x$, $y$; however, in some cases this more general type of transformation may prove very useful. An outstanding example is given by the Soret grating.

In a Soret grating the transmission coefficient is a periodical function of $\rho^2$, denoting by $\rho$ the distance from the center. Let $a$ be the period with respect to the variable $\rho^2$; it may also be said that the grating is periodical with respect to $\rho$, according to the variable period $a/2\rho$. We can then apply Eq. (3), obtaining

$$(n'\mathbf{s}_p'-n\mathbf{s}-p(\lambda'/a)\,\text{grad}\rho^2)\times\mathbf{k}=0. \tag{7}$$

The constant vector $\mathbf{d}$ is now replaced by a gradient and therefore the transformation (7) preserves the normality of an incident congruence. If the incident wave is spherical and centered on the axis, it is well known that the diffracted waves constitute a discrete set of spherical waves centered on the axis (paraxial approximation). Our generalization of the theorem of Malus-Dupin allows us to state that the diffracted waves form a discrete set, regardless of the shape of the incident wave. In this connection we note that it is possible to investigate the off-axis aberrations of a Soret grating.

## FERMAT'S PRINCIPLE

According to the above considerations we can speak, in the parageometrical field, of incident rays and diffracted rays. Let $\mathbf{r}=r\mathbf{s}$ be an incident ray, issuing from point $P$ of medium $n$ and impinging on the grating in point $O$; let $\mathbf{r}'=r'\mathbf{s}_p'$ be the diffracted ray in medium $n'$, going from point $O$ to point $P'$. The optical path along the ray is $nr+n'r'$. Suppose now that the ray follows a slightly different path, passing through the point $O'$ of the grating, located on the same groove as $O$, at a distance $dx$ apart from $O$. The optical path becomes then

$$n|r\mathbf{s}+dx\mathbf{j}|+n'|r'\mathbf{s}_p'-dx\mathbf{j}|,$$

$\mathbf{j}$ being a unit vector in the direction of the groove. Neglecting infinitesimals of a higher order than $dx$, the above expression can be written

$$n(r+dx\mathbf{s}\cdot\mathbf{j})+n'(r'-dx\mathbf{s}_p'\cdot\mathbf{j}).$$

This, by virtue of Eq. (2), reduces to $nr+n'r'$. Thus we find that the optical path actually followed by the ray is stationary, if compared with all the neighboring paths that pass through the same groove of the grating. This is the form Fermat's principle takes in parageometrical optics.

The principle is valid also for a continuous set of diffracted waves. The optical path of a **d**-ray is stationary with respect to all neighboring paths, passing through a line element of the $xy$ plane, perpendicular to $\mathbf{d}$.

If we consider the diffraction from a small zone near the edge of the aperture, the **d**-waves have a non-negligible intensity only when $\mathbf{d}$ is perpendicular to the edge. Then a light path going from the source to a given point in the geometrical shadow is stationary, if compared with all other paths that pass through neighboring points of the edge. We thus find Rubinowicz's principle[6] as a particular case of the variational principle of parageometrical optics.

We can now easily explain several phenomena of common observation. For instance, when looking at a point source through a transparent plate, one gets the impression that all the scratches existing on the plate surface are tangent to the circles, whose centers are on the line joining the eye with the source. This happens because (1) there are no other scratches admitting of a stationary path for a **d**-ray, with $\mathbf{d}$ perpendicular to the scratch, and (2) all **d**-waves whose $\mathbf{d}$ is not perpendicular to the scratch have zero intensity.

Again, as remarked by Kossel,[7] that diameter of a gramophone record which becomes luminous in the presence of a point source, corresponds to all the paths that go from the source to the eye, being stationary along the grooves. By means of the same principle Kossel explains the remarkable properties of the circular grating with random radii.

## LIOUVILLE'S THEOREM

The analogy existing between geometrical optics and analytical mechanics is well known.[8] If we denote with

[4] G. Toraldo di Francia, Nuovo Cimento **6**, 24 (1949).
[5] M. Herzberger, Math. Rev. **9**, 165 (1948).
[6] A. Rubinowicz, Ann. d. Physik **73**, 339 (1924).
[7] W. Kossel, Zeits. f. Naturforsch. **3a**, 496 (1948); **4a**, 506 (1949).
[8] C. Carathéodory, *Geometrische Optik* (J. Springer, Berlin, 1937), p. 19.

$q_1$ and $q_2$ respectively the coordinates $x$ and $y$ of a typical point on a given ray and with $p_1$ and $p_2$ the optical direction cosines $n\alpha$ and $n\beta$ of the ray, the following equations are valid

$$\begin{aligned} \dot{q}_1 &= H_{p1}, \quad \dot{p}_1 = -H_{q1}, \\ \dot{q}_2 &= H_{p2}, \quad \dot{p}_2 = -H_{q2}, \end{aligned} \tag{8}$$

where a dot denotes derivation with respect to $z$ and $H=-n\gamma=-(n^2-p_1^2-p_2^2)^{\frac{1}{2}}$. These canonical equations show that $q_1$, $q_2$ behave like the generalized coordinates of mechanics, $p_1$, $p_2$ being their conjugate momenta and $H$ the Hamiltonian.

Let us now consider a thin bundle of rays, whose principal ray passes through the point $q_1$, $q_2$ of the plane $z=0$, in the direction $p_1$, $p_2$. All the other rays of the bundle are contained in an infinitesimal range $dq_1dq_2dp_1dp_2$ around the principal ray. We shall call this product $dq_1dq_2dp_1dp_2$ the *optical volume* of the bundle. Now Liouville's theorem, which is well known in statistical mechanics, states that this volume is a constant, provided that the variation of the coordinates with $z$ is governed by Eqs. (8). The optical volume is therefore an invariant in geometrical optics.

Further we have

$$dq_1dq_2dp_1dp_2 = dSn^2d\alpha d\beta = dSn^2\gamma d\Omega, \tag{9}$$

where $\gamma dS$ is the normal cross section of the bundle for $z=0$ and $d\Omega$ its solid angle.[9] Thus, the invariance of the optical volume, together with the conservation of energy, bears as a consequence the invariance of the reduced brightness $B_0=B/n^2$ along the bundle.

Now it is seen by simple inspection of (1) or (4) that the optical volume is preserved also in parageometrical refraction. In other words the optical volume of a **d**-bundle equals the optical volume of the incident bundle. This fact has a remarkable thermodynamical meaning.[10,11] We see for instance, that the reduced brightness of a **d**-bundle can never exceed that of the incident bundle.

## CONCLUSION

As we have seen, it seems to be expedient to include between geometrical optics and wave optics a third branch with well-defined characteristic features, which we call parageometrical optics. Geometrical optics itself is only a particular case, which takes place when all **d**-waves, excepting the zero-wave, have vanishing intensity.

The whole argument rests on the assumption that the complex amplitude emerging from the $xy$ plane is proportional to the incident amplitude, independently of the angle of incidence. Only in that case does it have physical meaning to speak of a **d**-wave. This assumption is not rigorous, but proves to be extremely near to the truth in almost every case of interest in instrumental optics.

In this connection let us emphasize that when the highest degree of rigor is needed, geometrical optics also loses its validity inside its own domain; this is apparent, for instance, in the well-known problem of the reflection of a spherical wave at a plane surface separating two different media.[12]

It is evident that the arguments of this paper can also be applied for studying the transition from classical mechanics to wave mechanics.

[9] For geometrical optics the invariance of the right side of Eq. (9) was first demonstrated by R. Straubel, Physik. Zeits. **4**, 114 (1902).

[10] M. von Laue, Ann. d. Physik **30**, 225 (1909).

[11] G. Toraldo di Francia, Rend. Acc. Naz. Linc. **4**, 319 (1948).

[12] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941), p. 573.

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# The Ultimate Limits of Sensitivity of Lead Sulfide and Telluride Photo-Conductive Detectors

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(Received March 21, 1950)

Calculations are carried out for the theoretical limits of sensitivity of lead salt photo-conductive cells, on the basis of fluctuations in the room temperature radiation quanta falling on the cell. The results show a marked dependence on the temperature of the layer, and on the form of the spectral sensitivity curve.

Using cooled detectors exposed to room temperature radiation, it should be possible to detect $8\times10^{-14}$ watt at $2.9\mu$ with PbS, and $9\times10^{-13}$ watt at $5.0\mu$ with PbTe.

## INTRODUCTION

PHOTO-CONDUCTIVE layers of lead sulfide and lead telluride can now be made with sensitivities in the near infra-red region of the spectrum which are many times greater than for the conventional radiation detectors such as bolometers and thermopiles. Lead sulfide cells have been made which will give signal equal to r.m.s. noise in 1 c/sec. band width for an incident energy of about $10^{-12}$ watt in the $2\mu$ region, and even better sensitivities have been quoted for PbTe.[1]

Combined with rapid response times—$10^{-4}$ to $10^{-3}$ sec.—these high sensitivities make such layers excellent detectors for spectroscopy and other purposes, and it is thus of interest to find what factors limit the attainable sensitivity, and to calculate the limiting sensitivity of a perfect detector of this type.

Previous calculations of the limiting sensitivities of radiation detectors have already been published by Jones[2] and Fellgett.[3] In the present article calculations are carried out for various PbS and PbTe layers, with emphasis on the effects produced by different spectral sensitivity curves and by varying the layer temperature.

The fundamental limitation of sensitivity is imposed by fluctuations in the incident radiation. For cells of high sensitivity it is found that the dark conductivity is largely photo-conductive due to room temperature radiation—particularly when the layer is cooled. Gibson[4] has found that a layer of PbS at 90°K increased in resistance by over a hundred times on removing the room temperature radiation by cooling the cell surroundings. Simpson[5] has found an increase of 6:1 for PbTe under the same conditions. It thus seems probable that in these cells the sensitivity is actually limited by resistance fluctuations consequent upon the fluctuations in the incident stream of radiation quanta.

Since the layers are only sensitive to a portion of the spectrum, only quanta in the effective wave-length range should be considered. The total radiation will in fact produce fluctuations in the layer temperature, but since the cells are insensitive considered as bolometers, this effect will be ignored.

As the bulk of room temperature radiation lies at long wave-lengths, it is clear that cells sensitive to longer wave-lengths will receive more effective quanta. Thus the limiting sensitivity will differ for PbS and PbTe; and furthermore will vary with temperature due to the temperature dependence of the spectral range of sensitivity.[6]

## FLUCTUATIONS IN RADIATION

Using Bose-Einstein statistics, Fowler[7] gives for the fluctuations in the energy density of temperature radiation:

$$\langle(\rho d\nu-\bar{\rho}d\nu)^2\rangle_{Av}=h\nu\bar{\rho}d\nu+\frac{c^3}{8\pi\nu^2}.(\bar{\rho})^2d\nu,$$

where

$$\bar{\rho}=h\nu\bar{n}=\frac{8\pi\nu^2}{c^3}.\frac{h\nu}{\exp(h\nu/kT)-1},$$

and $\bar{n}d\nu$ is the average number of quanta in the frequency interval $d\nu$.

Hence $\langle(nd\nu-\bar{n}d\nu)^2\rangle_{Av}=\bar{n}d\nu\{1+1/(\exp h\nu/kT-1)\}$. For a temperature of 300°K and wave-lengths less than $6.0\mu$, $h\nu/kT>8$. So for these conditions the exponential term is very large compared with unity, and we obtain: $\langle(nd\nu-\bar{n}d\nu)^2\rangle_{Av}=\bar{n}d\nu$, for example, classical statistics may be used. The same treatment applies to fluctuations in the number of quanta striking a surface. If $n_a$ quanta strike area $a$ per unit time, then $\langle(n_ad\nu-\bar{n}_ad\nu)^2\rangle_{Av}=n_ad\nu/\tau$, where $\tau$ is the time of observation. If all the quanta occur in a narrow band of frequencies, we may replace $n_ad\nu$ by $N_a$, the total number of quanta/sec. and obtain $\langle(\Delta N_a)^2\rangle_{Av}=N_a/\tau$.

## CURRENT FLUCTUATIONS IN THE LAYER

Suppose the properties of the layer are such that $N$ quanta absorbed per second give a current $meN$, where $m$ is a factor determined by the quantum efficiency and the effective distance traveled by a photo-electron between the electrodes. In a time interval $\tau$ the fluctuation

[1] O. Simpson, G. B. B. M. Sutherland, and D. E. Blackwell, Nature **161**, 281 (1948).
[2] C. Jones, J. Opt. Soc. Am. **37**, 879 (1947).
[3] P. Fellgett, J. Opt. Soc. Am. **39**, 970 (1949).
[4] A. F. Gibson, T.R.E. Memo. L3/51/AFG, 1948.
[5] O. Simpson, Proc. Phys. Soc. **61**, 486 (1948).
[6] T. S. Moss, Proc. Phys. Soc. **62**, 741 (1949).
[7] R. H. Fowler, *Statistical Mechanics* (Cambridge, London, University Press, 1936), second edition.

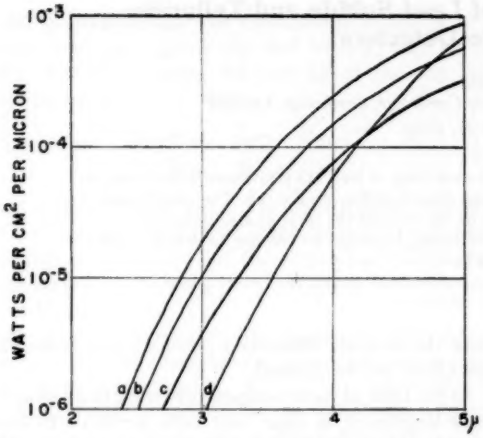


FIG. 1. Blackbody radiation curves. (a) 300°K; (b) 290°K; (c) 273°K; (d) 200°K (scale ×1/100).

in $N$ will be $\langle(\Delta N)^2\rangle_{Av}=N/\tau$. Hence the current fluctuation will be $\langle(\Delta i)^2\rangle_{Av}=m^2e^2N/\tau$ if no additional fluctuations are introduced by $m$. There is at present no evidence to show whether additional current noise occurs in photo-conductive cells through fluctuations in the quantum efficiency or not. Presumably it would depend on individual cells (being low in "good" cells) and is thus essentially a practical limitation dependent on the manufacture of the cell. In the present discussion, as the aim is to find the theoretical limit of sensitivity set by fluctuations in the radiation alone, fluctuations in $m$ will be ignored. It may be noted that in some cells the measured sensitivity approaches close to the limit thus calculated, indicating that in these cells at least, fluctuations in $m$ cannot be large.

We will define the limiting sensitivity of a layer as being that radiation required to produce a signal equal to the r.m.s. noise from the layer, for example, signal power+noise power=twice noise power. It may be noted that with this definition fluctuations in the signal itself are immaterial.

Suppose the room temperature radiation falling on the layer to be replaced by an effective power $P$ of radiation of wave-length $\lambda$, falling on a layer of constant sensitivity equal to the maximum sensitivity of the actual layer. The current fluctuation will then be $\langle(\Delta i)^2\rangle_{Av}=m^2e^2N/\tau$, where $N$ is the number of absorbed quanta appropriate to the power $P$. Similarly a signal power $P_s$ at the wave-length $\lambda$ will be equivalent to $P_sS_\lambda$ at this wave-length falling on a layer of constant sensitivity equal to the maximum sensitivity of the layer; $S_\lambda$ being the relative sensitivity. If the number of absorbed quanta appropriate to $P_sS_\lambda$ is $N_s$, the resulting signal will be

$$i_s^2=m^2e^2N_s^2$$
$$=m^2e^2N/\tau \text{ by definition.}$$

Hence $N_s^2=N/\tau$.

Now it may be shown[8] that an observation time $\tau$ is equivalent to the reciprocal of twice the band width of the measuring instrument. Hence $N_s^2=2N\Delta f$, or $N_s^2=2aN_0$ for a layer area $a$, $N_0$ quanta/cm²/sec. and 1 c/sec. band width. It will be observed that this expression is independent of the parameter $m$.

When incident as opposed to absorbed quanta are considered, account should be taken of the reflection and transmission coefficients ($r$ and $t$ say) for the layer. If $N_s'$ and $N_0'$ are used for incident quanta, then $N_s'=\{2aN_0/1-r-t\}^{\frac{1}{2}}$.

Most PbS and PbTe cells have low transmission, and about 30 percent reflection coefficient. Thus $(1-r-t)^{\frac{1}{2}}=0.85$ approximately. This factor is relatively unimportant, and will not be considered in the rest of the calculations; i.e., $N_0'$ and $N_s'$ will be taken as equal to $N_0$ and $N_s$ respectively.

## LEAD SULFIDE LAYERS

Figure 1 shows curves of the spectral distribution of the energy radiated by a blackbody to cold space for various temperatures near room temperature for a solid angle of $2\pi$. Hence these curves give the energy distribution of room temperature radiation falling on a cooled layer.

Figure 2 shows the spectral distribution of the sensitivity of a PbS layer to an equal energy spectrum for layer temperatures of 290°K and 90°K.[6]

Multiplying the curves of Figs. 1 and 2 together, and integrating the area under them, will give the equivalent energy falling on a layer of constant energy sensitivity. Such a product curve (for a layer at 290°K with blackbody radiation of 290°K falling on it) is shown in Fig. 3. It is seen that the effective wave-lengths are limited to a narrow band centered on 2.9$\mu$; and therefore to good degree of approximation the quanta may be considered to have all one energy value—i.e., that appropriate to

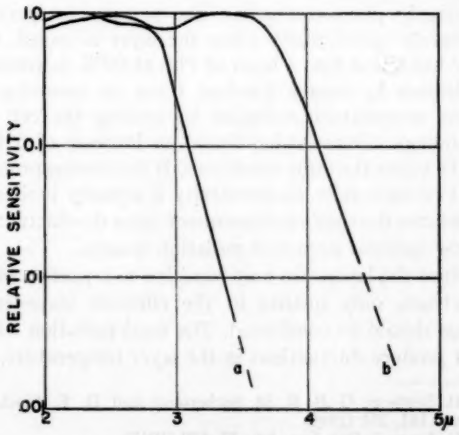


FIG. 2. Lead sulfide spectral sensitivity curves. (a) 290°K; (b) 90°K.

[8] J. M. W. Milatz, Ned. T. Natwurk, 8, 19 (1941).

2.9$\mu$. It may be noted that the product curve has a symmetrical appearance. If it is truely symmetrical then the effective energies at two wave-lengths spaced $\pm\Delta\lambda$ from the peak wave-length $\lambda$ will be the same, say $E d\lambda$. The number of quanta in the two bands will be $E(\lambda-\Delta\lambda)d\lambda/h$ and $E(\lambda+\Delta\lambda)d\lambda/h$. Thus the total from the two bands is $2E\lambda d\lambda/h$, or the same as if the bands were considered as having their combined energy at the central wave-length. Thus any error in considering all the quanta to be of the peak wave-length will be small.

By graphical integration the total equivalent energy falling on a layer of constant sensitivity equal to the peak sensitivity of the actual layer is found to be $1.96\times10^{-6}$ watt. Now $h\nu=0.68\times10^{-19}$ joule at 2.9$\mu$, and hence the effective number of quanta falling on the layer is $N_0=2.9\times10^{13}$/cm$^2$/sec.

For electrodes 0.1 cm$^2$ in area and for 1 c/sec. band width, $N_s=2.4\times10^6$ quanta/sec. At 2.9$\mu$ this would be equivalent to $1.63\times10^{-13}$ watt. Now this $=P_sS_\lambda$, and since $S_\lambda$ at this wave-length is 0.58, the limiting sensitivity at 2.9$\mu$ will be $2.8\times10^{-13}$ watt. At the wave-length of maximum sensitivity, i.e., 2.3$\mu$, limiting sensitivity $=1.63\times10^{-13}$ watt.

These figures are for an active area of layer of $1\times0.1$ cm$^2$, which is the size of layers as normally manufactured at present. The minimum area of detector feasible for use on a spectrometer and from manufacturing points of view is about $3\times0.3$ mm$^2$ or say $10^{-2}$ cm$^2$. Since the noise power is proportional to area, this area would reduce the limiting sensitivity to $5.2\times10^{-14}$ watt at 2.3$\mu$.

In considering an uncooled layer, allowance should be made for the fact that radiation will be falling on both sides of the layer. For all the other cases considered later in this paper, the layer backing is cooled so that radiation falling on one side only has to be considered. To make the conditions the same for all cases, it will be considered that the layer above is slightly cooled (to the region of 0°C) so that radiation on the back of the layer may be neglected compared with that on the front. Such a moderate degree of cooling would have little effect on the spectral sensitivity curve. This procedure has the added advantage that radiation emitted by the layer may be neglected.

For the same layer at 90°K the product curve for 290°K radiation has the peak at 3.7$\mu$. The effective total incident energy is $4.6\times10^{-5}$ watt, corresponding to $N_0=8.7\times10^{14}$ quanta. Hence at this wave-length of 3.7$\mu$ and for a $10^{-1}$ cm$^2$ layer the limiting sensitivity $=8.8\times10^{-13}$ watt; and $2.8\times10^{-13}$ watt for $10^{-2}$ cm$^2$ area electrodes. At the optimum wave-length of 3.5$\mu$ the limiting sensitivity for a $10^{-2}$ cm$^2$ layer is $2.2\times10^{-13}$ watt.

When a cell is operated at liquid air temperature, the local temperature round the cell becomes lowered somewhat. It is quite possible that the temperature of the incident radiation falling on the layer falls to 0°C, and

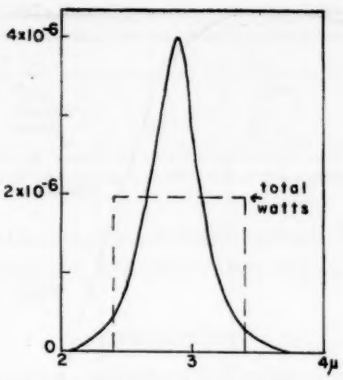


FIG. 3. Product curve with equivalent energy on uniformly sensitive layer plotted in watts against wave-length.

it is of interest to see how this affects the limiting sensitivity.

For this case $N_0=4\times10^{14}$, for example, the cooling about halves the value of $N_0$. Hence at 3.5$\mu$ for $10^{-2}$ cm$^2$ electrodes, the limiting sensitivity $=1.5\times10^{-13}$ watt.

It is found that the spectral distribution of sensitivity varies somewhat for different PbS cells, particularly when they are made by different techniques. The cell whose curves are shown in Fig. 2 was an early chemical type, and the threshold wave-length for this layer at 90°K was one of the greatest which have been measured. Figure 4 shows a modern cell as manufactured by B.T.H. Company, Rugby, and this represents approximately the minimum threshold wave-length measured. For this latter cell at 90°K and radiation at 0°C, the product curve peaks at 3.4$\mu$. It may be noted that this type of cell is made in a Pyrex envelope whose transmission is poor beyond 2.8$\mu$. Hence radiation of wave-lengths greater than 2.8$\mu$ (which constitutes over 90 percent of the effective radiation in this case), comes mainly from the glass envelope, not through it. The temperature of the envelope may easily fall to 0°C due to the liquid oxygen coolant round the layer.

For this case, the effective number of quanta incident on the layer is $N_0=8.3\times10^{13}$/cm$^2$/sec., whence

$$N=8.3\times10^{12} \text{ for } 10^{-1} \text{ cm}^2 \text{ electrodes,}$$

and

$$8.3\times10^{11} \text{ for } 10^{-2} \text{ cm}^2 \text{ electrodes.}$$

At the optimum wave-length of 2.8$\mu$, we find

$$\text{limiting sensitivity} = 2.4\times10^{-13} \text{ and } 7.7\times10^{-14} \text{ watt}$$

respectively.

The above results are summarized in Table I which shows the limiting sensitivities at various wave-lengths for three cases:

(a) 1st cell at 273°K with 290°K radiation,
(b) 2nd cell at 90°K with 273°K radiation,
(c) 1st cell at 90°K with 273°K radiation.

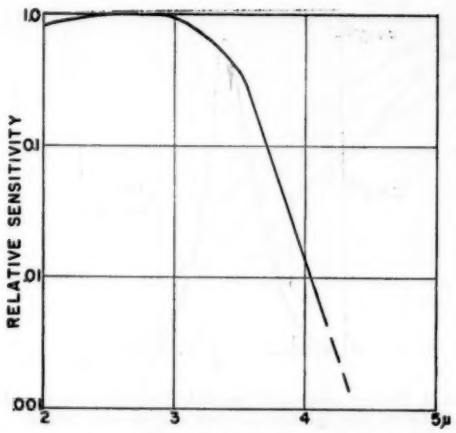


FIG. 4. Spectral sensitivity of lead sulfide at 90°K.

The table shows that at the wave-length of 2.3$\mu$ the limiting sensitivity of the first cell is worsened by a factor of 3 on cooling to 90°K. Also we see that as the wave-length of maximum sensitivity increases (from (a) to (c)), the limiting sensitivity becomes considerably worse. Thus it is inefficient to use a layer with appreciable sensitivity at wave-lengths greater than the wave-length of the desired signal.

The figures in the table may be compared with published measurements. Fellgett[3] found a limiting sensitivity of $5\times10^{-13}$ watt for a 0.2 cm$^2$ layer at 195°K. This would correspond to $11\times10^{-14}$ watt for the same area as used for the figures in the table.

Watts[9] has carried out measurements on cooled PbS cells, with and without the surroundings cooled. He remarks that in general, cooling the surroundings to liquid oxygen temperature increased the sensitivity 10 to 20 times. In one case a limiting sensitivity of $2\times10^{-13}$ watt/cm$^2$ was obtained. The area of this layer was 0.1 cm$^2$;* so for a $10^{-2}$ cm$^2$ layer the equivalent sensitivity would be $0.65\times10^{-14}$ watt. This is clear evidence that the limit imposed by fluctuations in the incident radiation was reached by this cell when operated in room temperature surroundings.

The spectral sensitivity distribution for this cell is presumably similar to that in Fig. 4, and hence the figure of $0.65\times10^{-14}$ watt is a factor of 12 better than the theoretical limit when room temperature radiation is present. For the cell of Fig. 4 operated at 90°K in surroundings at 200°K (i.e., approximately solid carbon-dioxide temperature) the calculations give:

$$N_0=4\times10^{11} \text{ quanta cm}^2/\text{sec}.$$

Hence $N_s=9\times10^4$ for a $10^{-2}$ cm$^2$ layer. Hence at 2.9$\mu$, limiting sensitivity is $0.5\times10^{-14}$ watt for $10^{-2}$ cm$^2$ layer. This indicates that Watts had almost reached the fundamental limit appropriate to a radiation temperature of 200°K.

It is evident from the above figures that when extreme sensitivity is required, it may well be worth cooling the cell surroundings. Present indications are that cooling with solid $CO_2$ would be adequate to reduce radiation fluctuations to the level where they no longer impose a limit on the attainable sensitivity.

## LEAD TELLURIDE LAYERS

Similar calculations apply for PbTe; it is only necessary to use the appropriate spectral sensitivity curves.

Figure 5a shows a spectral sensitivity curve for PbTe at 90°K.[6] Assuming 273°K radiation falling on to this layer a product curve of radiation and sensitivity is plotted as before. The resulting curve is broader than for the PbS cases, but is fairly symmetrical about the peak wave-length of 4.8$\mu$. From the area we find $N_0=61\times10^{14}$ quanta/cm$^2$/sec. Hence for $10^{-2}$ cm$^2$ layer $N_s=11\times10^6$ quanta/sec. Thus at 4.8$\mu$ the limiting sensitivity is $6.8\times10^{-13}$ watt; and at maximum sensitivity, for example, at 3.9$\mu$ or less, limiting sensitivity $=4.5\times10^{-13}$ watt.

A different form of spectral sensitivity curve has been given by Simpson *et al.*,[1] and is shown in Fig. 5b (for liquid air temperatures). For this curve with area and temperature conditions as above, we find $N_0=24\times10^{13}$ quanta/cm$^2$/sec. Hence at 4.1$\mu$ the wave-length of the peak of the product curve, the limiting sensitivity is $17\times10^{-13}$ watt; and is $1.1\times10^{-13}$ watt at the optimum wave-length, 1.8$\mu$.

Young[10] has recently measured two different types of spectral sensitivity curve, depending on the treatment given to the layer. One type is similar to that shown in Fig. 5a; the other is somewhat like that of Fig. 5b, except that the sensitivity falls off at still shorter wave-lengths. This latter curve is shown at Fig. 5c. It has not

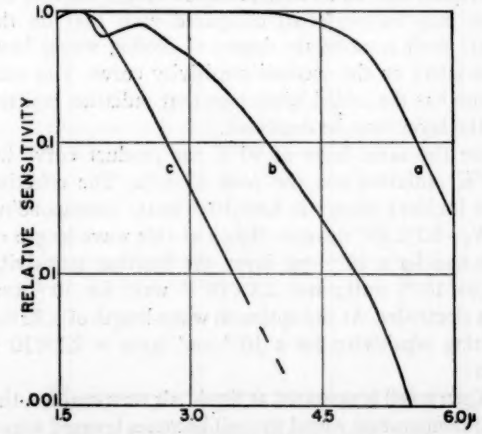


FIG. 5. Spectral sensitivity curves for lead telluride at 90°K.

[9] B. N. Watts, Proc. Phys. Soc. **62**, 457 (1949).
* Private communication from B. N. Watts.

[10] A. Young, T.R.E. Memo. No. 21, 1949.

TABLE I. PbS: Limiting sensitivities (units of $10^{-14}$ watt).†

| Wave-length | 2.3μ | 2.9μ | 3.5μ |
|---|---|---|---|
| (a) | 5.2* | 8.8 | 2000 |
| (b) | 8.3 | 7.7* | 22 |
| (c) | 17 | 17 | 15* |

† All figures for $10^{-2}$ cm² electrodes.
* Optimum wave-lengths.

TABLE II. PbTe. Limiting sensitivity in units of $10^{-13}$ watt.†

| Type of Cell | 1.8μ | 3.9μ | 5.0μ |
|---|---|---|---|
| Made by: Moss | 4.5 | 4.5* | 9 |
| Simpson | 1.1* | 11 | 130 |
| Young | 0.2* | 66 | >1000 |

† All figures for $10^{-2}$ cm² layer at 90°K with 273°K radiation.
* Optimum wave-lengths.

been measured to sufficiently long wave-lengths to enable a complete product curve to be plotted, but since the sensitivity falls at the rate of about 16:1 per micron increase of wave-length beyond 2.0μ, it will be assumed that it would continue to fall at the same rate. With conditions as before, this leads to an estimated limiting sensitivity of $2\times10^{-14}$ watt at the optimum wave-length 1.8μ.

The limiting sensitivities of these three types of cell at various wave-lengths are listed in Table II.

Comparison of Tables I and II shows that the limit for a cooled long wave-length-sensitive PbTe cell is about ten times worse than an uncooled PbS cell in the 2μ region of the spectrum. Also it is approximately ten times better than a "black" thermal detector of the same area.

The most sensitive cell measured by the author (which probably had a spectral sensitivity curve similar to Fig. 5a) gave a signal equal to r.m.s. noise in 1 c/sec. band width for $1.5\times10^{-11}$ watt radiation from a tungsten lamp at roughly 2000°K. The area of the layer was $1.6\times10^{-2}$ cm².

For a cell similar to that shown in Fig. 5b Simpson[5] reports a measured sensitivity of $2\times10^{-14}$ watt for a layer $10^{-2}$ cm². This was an indirect measurement, which may account for the fact that this sensitivity is several times better than the theoretical limit calculated for a cell with a spectral sensitivity curve as published by Simpson.

Nevertheless, the figures clearly indicate that PbTe cells can be made with sensitivities very near to the theoretical limit.

## CONCLUSIONS

The limiting sensitivities of lead sulfide and telluride detectors are calculated on the assumption that the limit is imposed by fluctuations in the radiation quanta falling on the sensitive layers. The figures obtained are greatly dependent on the form of the spectral sensitivity curve, values differing by a factor of 20:1 resulting from the different curves reported for PbTe. For a PbTe cell sensitive to 5.0μ, the detection limit is ten times worse than for a PbS cell sensitive only to 2.9μ. The improvement in limiting sensitivity obtained by using a photoconductive detector instead of a thermal detector will not be great for signal wave-lengths more than 5.0μ. Cooling the detectors worsens the limiting sensitivity in consequence of the shift of the spectral sensitivity curves to longer wave-lengths.

An improvement of fifteen times in the detection limit of a PbS cell may be realized (theoretically) by cooling the cell surroundings with solid carbon dioxide.

## ACKNOWLEDGMENTS

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# A Rapid Scanning Spectrometer for Oscillographic Presentation in the Near Infra-Red*

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A rapid scanning spectrometer for oscillographic presentation has been built for use in the "photo-conductive" infra-red region. It is designed to present spectra from 0.36$\mu$ to better than 5$\mu$ using a PbTe cell. The $CO_2$ doublet at 4.2$\mu$ is resolved with a scanning rate of 120 cycles per second and a scanned interval of better than 1.5$\mu$ with fluorite optics. A wave-length calibrating device has been incorporated into the instrument; this presents a fiduciary scale, synchronized with the spectrum, on the second beam of the twin-beam cathode-ray oscillograph. Adequate solutions have been found for the problems of synchronizing oscilloscope sweep and scanning drive, and for the problems of amplifier design for the sensitive cells.

## INTRODUCTION

In recent years there have been a number of developments in the general field of rapid scanning spectroscopy. Daly and Sutherland[1] have described a quite successful spectrometer for use in the infra-red with oscillographic recording. Another spectrometer of this type was described by King, Temple, and Thompson.[2] A similar instrument of somewhat faster response was designed in cooperation with the Perkin-Elmer Corporation and described by one of us.[3] Very recently, an elegant commercial instrument for oscilloscope presentation and recording has been described by Menzies.[4] These instruments all have recording times of from one to several seconds per octave. Recently, too, very rapid recording spectrometers for the visible and ultraviolet have been described using photo-cells as receiving devices.[5,6]

It was apparent that the advent of photo-conductive cells for use in the infra-red had opened the possibility of building a rapid response infra-red spectrometer for cathode-ray oscillograph presentation. Accordingly, the authors began work on such a spectrometer about a year and a half ago, and described an early prototype.[7] This prototype has now been greatly improved both in performance and appearance and is described below.

## DISCUSSION OF PROBLEMS OF GENERAL DESIGN

Our instrument was designed primarily to study combustion problems of emission and absorption spectra many of which are of a transient nature. It was necessary to take into account not only the fact that high speed of response would be required, but also the fact that some of these combustion studies eventually would be carried out in plant areas under what one might consider unfavorable laboratory conditions. Accordingly, we have set for our goal (1) an instrument whose speed of response is maximized in accordance with time constants of existing receivers; (2) adequate C.R.O. presentation with reliable means for permanent recording; (3) good optical design; (4) a means of direct, instantaneous, and continuous wave-length calibration; (5) packaging of various components in sub-assemblies wherever possible to permit ease of readjustment, repair, and replacement; and (6) sufficient portability to permit use of the instrument outside the confines of our laboratory.

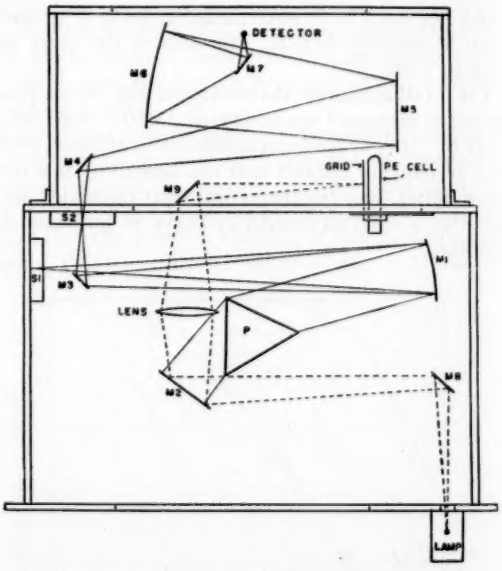


FIG. 1. This is a schematic drawing of the spectrometer.

S1, S2 entrance and exit slits
M1 f-5, 3 in. 15° off-axis parabola
M2 Littrow mirror 6×8×0.4 cm
M3, M4 Newtonian mirrors 2.5×2.5 cm
M5, plane mirror
M6, 4 in. ellipse, foci 10 and 60 cm respectively
M7, plane mirror
P, $CaF_2$ prism
Lamp—6 volt, 1A, straight filament G.E. galvanometer lamp
Lens—165 mm, $f$ 4.5 Kodak Ektar projection lens
M9, plane mirror
M8, plane mirror

* This work was supported by ONR and Navy Bureau of Ordnance under Contract NOrd-7836.

[1] E. F. Daly and G. B. B. M. Sutherland, Proc. Phys. Soc. (London) 59, 77 (1946).
[2] J. King, R. B. Temple, and H. W. Thompson, Nature 158, 196 (1946).
[3] S. Silverman, J. Opt. Soc. Am. 38, 664A (1948).
[4] A. C. Menzies, J. Opt. Soc. Am. 39, 1060A (1949).
[5] R. Feldt and C. Berkeley, National Electronics Conferences, Chicago, 1946.
[6] W. E. Deal, W. Bradshaw, and F. A. Matsen, J. Chem. Phys. 38, 209 (1948).
[7] B. W. Bullock and S. Silverman, J. Opt. Soc. Am. 39, 200 (1949).

## DESCRIPTION OF THE INSTRUMENT

The optics of the instrument are shown schematically in Fig. 1. The solid lines denote the path of radiant beam itself, whereas the dotted lines indicate the path of the optical calibration system which is described below in detail. The design is quite conventional in most respects. The principal items of interest are the mirror, $M_2$, which is the Littrow mirror and its mounting. This mirror is mounted on a shaft perpendicular to the base of the spectrometer. In addition to the usual micrometric screw method of rotation about an axis in the plane of the mirror, a means is provided for producing a *rapid* vibration of as much as 2° of $M_2$ to produce a rapid scan of the spectrum across the exit slit. A micrometer screw allows one to set the mirror when static on any given wave-length, and the vibration then produces a sweeping spectrum centered at this setting. The vibrating mirror is driven by a torque motor whose natural frequency is about 300 c.p.s. Coupling is made directly through a short length of tightly wound helical spring soldered to a $2\frac{1}{2}$ in. length of $\frac{1}{16}$ in. drill rod. This latter is clamped to the drive arm of the torque motor. The pivots of the mirror are glass hardened steel points and ride on four-ball miniature bearings. The torque motor is an integral part of the mirror assembly and rides on the arm that is moved by the positioning micrometer screw. $M_2$ is $6\times8\times0.4$ cm, with a moment of inertia of about 200 g cm$^2$ and can be driven up to 150 c.p.s. with usable amplitude. The spring link in the driving assembly permits just enough lateral play to prevent snapping of the $\frac{1}{16}$ in. drive rod.

The prism is inverted in relation to the usual position to allow room for the scanning gear, and $M_6$ is an oversized elliptical mirror of which a portion is used in an off-axis manner. The $CaF_2$ prism was furnished by Perkin-Elmer Corporation in one of their usual mounts and it may be readily interchanged with other prisms. The slits are conventional commercial ones supplied by Gaertner, except for the fact that curved jaws were used for the entrance slit.

The spectrometer proper has a separate box for the optics following the exit slit. The radiation is focused on the reciver by the above-mentioned elliptical mirror used in the off-axis manner. The detectors used were PbS, PbSe, and PbTe cells.

The calibration is achieved optically and is essentially an angle measuring device. An image of a bright straight filament galvanometer lamp is formed on a grid in front of a photo-cell as shown by the dotted line ray diagram in Fig. 1. The grid itself is shown in Fig. 2. As the Littrow mirror vibrates the line moves across the grid and a series of pulses is received by the cell and transmitted to the C.R.O. Every tenth clear space is blacked out, and each decade has its decade index number half-blackened. As a result the trace seen on the scope is approximately a sine wave with certain pulses missing and others of half-strength unambiguously defined and

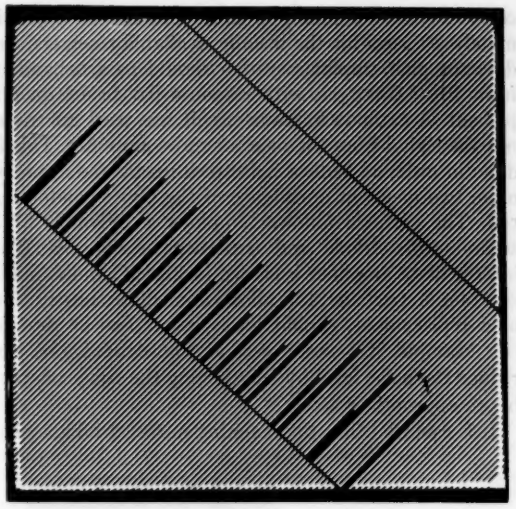

FIG. 2. This figure shows the calibration grid, with its decade markings.

the deflection angle in fiduciary terms is automatically locked in with the motion of the dispersing system. Accordingly each point on the calibration cycle will always correspond to the same point on the wave-length sweep cycle. A reading accuracy of 0.01$\mu$ is obtainable with a $CaF_2$ prism in the region 1–5.5$\mu$, using known absorption bands for reference wave-lengths.

The spectra are recorded on a DeVry 35-mm camera which has been made into a continuous strip camera by removing the shutter and pull-claw mechanism. The camera has an $f$ 1.5 lens, and obtains excellent traces at 150 c.p.s. with a sweep time of about 2 msec. per sweep using Eastman Kodak Super XX film and a P-7 long persistence screen. This screen is bright enough for photography, and has the additional advantage of permitting visual comparisons of several traces in a given sequence. Film transport is maintained at about 20 in. per second, using the original spring drive which is quite satisfactory since film comes up to full speed in about 0.05 sec. The entire instrument is mounted on a relay rack set upon a dolly as shown in Fig. 3.

## ELECTRICAL CIRCUITS

The block diagram is shown in Fig. 4. A DuMont 279 double beam C.R.O. is used; one beam is used for the spectrum trace, and the second beam is used for the wave-length calibration. A Hewlett-Packard 200 *I* audio oscillator provides a sine wave output of variable frequency which is fed to an amplifier which in turn supplies the power for driving the Littrow mirror, the voltage for driving the sweeps for the C.R.O. and a beam-blanking voltage for the "*Z*" axis of the oscilloscope which will be mentioned later in more detail.

The detector amplifier system merits some special

consideration. Assuming a time constant of approximately 30 $\mu$sec. for the usually available receivers, the detector plus amplifier system should pass a band of from 10–35,000 c.p.s. with response flat to five to ten percent. A cathode follower circuit was used to transmit the signal from the receiver to its amplifier. This is done in order to reduce noise pick-up by the approximate two megohm impedance of the photo-conducting cell. The cathode follower employs a Sylvania 5718 subminiature triode and is shown in Fig. 5B. The intermediate amplifier is shown in Fig. 5C and is made as a plug-in package; this allows immediate substitution of a replacement, should lower band pass be desired (for example, if a slower response be desired, one can reduce the noise level by lengthening the time constant by an appropriate factor).

It is essential that the scanning mirror driving signal

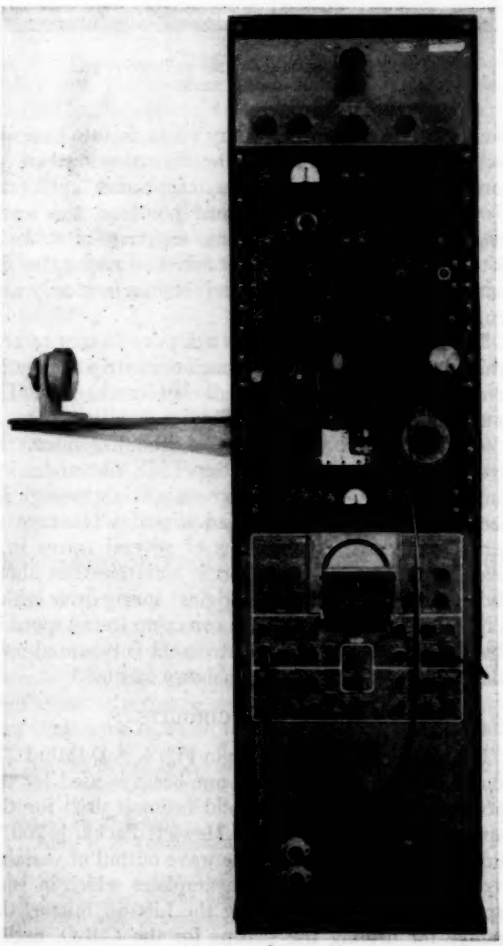

FIG. 3. This figure illustrates the complete assembly, with the C.R.O. screen partially obscured by a plane mirror which deflects the image vertically to the camera.

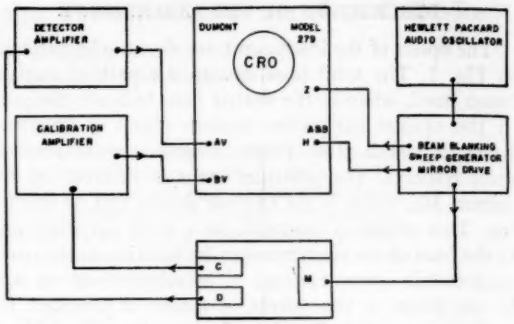


FIG. 4. This figure is a block diagram of the spectrometer and its associated parts.

and the sweep voltage be synchronized to present the spectrum on the screen at the desired time. The two sweeps are tied together, being driving by a common voltage signal supplied by the audio oscillator through amplifier, Fig. 4. This amplifier supplies the power (several watts) for driving the torque motor for the Littrow mirror drive, the sweep voltage for the C.R.O., and a beam blanking voltage for the "*Z*" axis of the oscilloscope to blank out the beam during the unused part of the sweep cycle. In addition the amplifier contains phase shifting networks to restore the proper phase relationships between the sweep and Littrow drive, for these are upset by the different treatment that these two signals undergo in their respective circuits.

It would be very desirable to have a linear sawtooth driving motion imparted to the Littrow mirror, but the moment of inertia (approximately 200 g cm$^2$) so loads the system that one obtains very nearly a sine wave. However, it is desirable to obtain a more linear relationship between wave-length and time on the scope screen. Therefore, the sine wave signal fed to the sweep circuit is distorted by rectification and a resistance network to give an essentially sawtooth wave form for about 60 percent of the original cycle. The sweep is blanked out for the unwanted portion of the cycle leaving approximately $-60°$ to $+60°$ of the original wave showing on the scope. This means then that roughly one-third of the mirror motion is used for spectrum presentation and the rest is discarded as "dead-time." The phase shift between the sweep and beam blanking circuits is adjusted by means of a phasing resistance condenser network. This circuit is shown in Fig. 6, together with the mirror drive amplifier.

It is essential that the noise level of the system be held to a minimum. Therefore, the photo-conducting cell was built into a small shielded housing containing the cathode follower Sylvania No. 5718 which was connected directly to the receiver leads. The cathode follower serves as a low impedance source for the intermediate amplifier whose output in turn feeds the "*A*" channel of the DuMont 279 scope. The noise level can

thus be maintained at around twice the Johnson noise of an equivalent resistor, provided one exercises reasonable care in selection of tubes and in shielding of the various components.

The calibration signal detector is an RCA 868 photocell. It is coupled to the calibration amplifier which in turn feeds channel *B* of the 279 scope. As mentioned above the *X*-axes of both *A* and *B* channels are tied together and a common sweep is applied. Since the C.R.O. tube is so constructed that deflections of the two tube beams are identical for equivalent excitation, positive synchronism of signal and calibration is maintained at all times. The calibration amplifier is designed for response from 600 to 15,000 cycles. There is no need here for linearity of response, and none was provided for, since the calibration merely consists of a set of signals spaced in time.

The frequency of scan as well as the amplitude of vibration may be controlled as desired. The frequency control is obtained from the Hewlett-Packard vernier and the amplitude is controlled by a volume potentiometer in the input of the motor drive amplifier. These two controls determine the frequency of scan and the wave-length interval encompassed in each scan, and therefore in part determine the resolving power of the instrument as discussed below.

## DISCUSSION OF INSTRUMENT PERFORMANCE

It is evident that there are certain boundary conditions for the behavior of a rapid-scanning spectrometer. To begin with, the resolving power is now determined by the response time of the receiver and circuit as well as by the optics, and in fact, is usually governed by the former. The general limit on resolving power is determined as follows. If $\tau$ is the response time of the receiving system, and $\Delta\lambda$ is the wave-length interval swept during the transit time $P$, then the smallest wave-length interval $d\lambda$ by which two signals can be separated

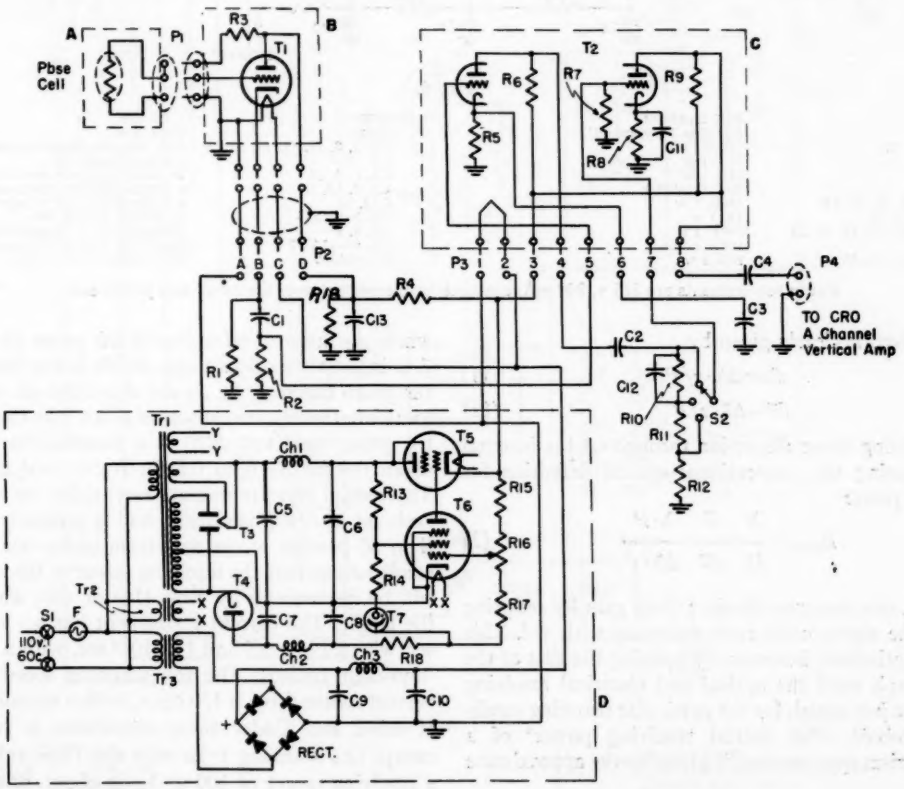


FIG. 5.

| | | | |
|---|---|---|---|
| R1, 11, 12 | 50K 1 w | T3, 4 | 6X4 |
| R2, 15 | 1 meg. 1 w | T5 | 6V6 |
| R3 | 3 meg. 1 w | T6 | 6AU6 |
| R4, 13 | 10K 1 w | T7 | 5651 |
| R5, 8 | 1K 1 w | Tr1 | Stancor P6011 |
| R6, 9, 10, 16 | 100 K 1 w | Tr2 | Stancor P6134 |
| R7 | 10 meg. 1 w | Tr3 | Stancor P6138 |
| R14, 17 | 25K 1 w | Ch1, 2 | Stancor C1708 |
| R18 | 30K 1 w | Ch3 | 1 henry, 4 ohm, 1 amp. |
| T1 | 5718 miniature triode | Rect. | Seletron *D1B1M1A* 1.2A 28V |
| T2 | 12AX7 | | |

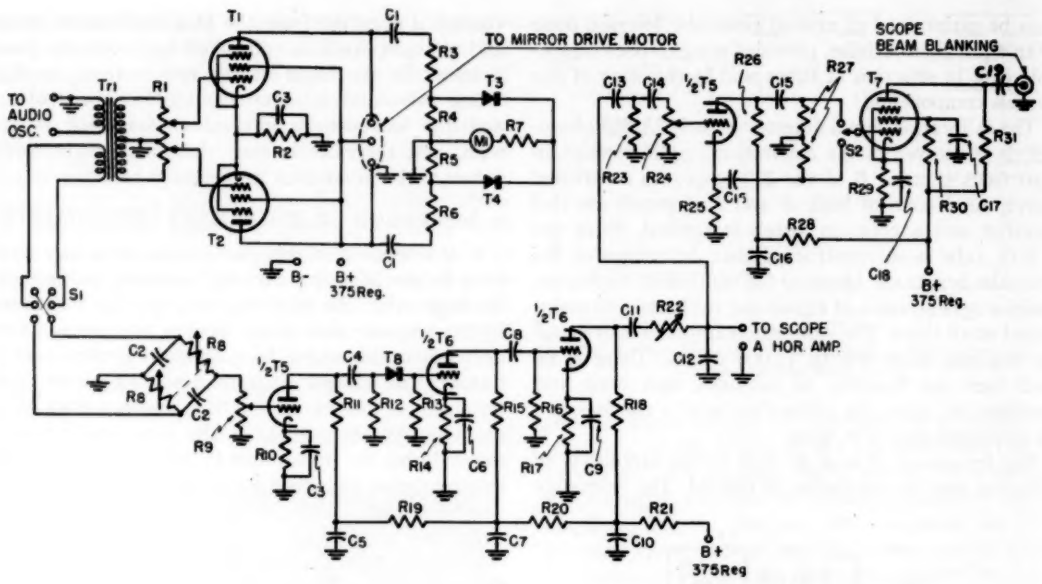


FIG. 6.

| | | | |
|---|---|---|---|
| R1 | 50K Dual Pot. | R29 | 1.1K 1 w |
| R2 | 500 ohm 25 w ww adj. | R30 | 550K 1 w |
| R3, 6, 31 | 220K 1 w | C1, 4, 8, 11, 13, 14, 15, 19 | 0.05 microfarad 400 v paper cond. |
| R4, 5 | 24K 1 w | C2 | 1.0 microfarad 200 v |
| R7 | 15K 1 w | C3, 6, 9, 18 | 20 microfarad 50 v electrolytic cond. |
| R8 | 50K Dual Pot. | C5, 7, 10, 16 | 8 microfarad 450 v electrolytic cond. |
| R9, 13, 16, 23, 24 | 250K 1 w | C12, 17 | 0.1 microfarad 400 v paper cond. |
| R10, 14, 25 | 3K 1 w | T1, 2—6L6G | S1 DPDT Toggle Sw. |
| R11, 12, 15, 18, 26, 27 | 100K 1 w | T3, 4, 8 | 1N34 S2 SPDT Toggle Sw. |
| R17 | 300K 1 w | T5, 6—12AU7 | Tr1 *UTC*, A-18 P.P. interstage |
| R19, 20, 21, 28 | 10K 1 w | T7—6AU6 | M1 Tripplet 3 in. 1 Mill. |

Power requirements are 375 v, 200 mA, constant to one percent over the range zero to full load.

and resolved is clearly given by

$$d\lambda=\Delta\lambda\cdot\tau/P \tag{1}$$

$$d\tilde{\nu}=\Delta\tilde{\nu}\cdot\tau/P \tag{1a}$$

and assuming linear dispersion throughout the internal $\Delta\lambda$ and using the conventional optical definition for resolving power

$$R_{\text{scan}}=\frac{\lambda}{d\lambda}=\frac{\tilde{\nu}}{d\tilde{\nu}}=\frac{\lambda\cdot P}{\Delta\lambda\cdot\tau}. \tag{2}$$

However, one does not obtain a clear gain by reducing $\tau$ since the signal/noise ratio decreases with $\tau^{-\frac{1}{2}}$. This may be optimized, however, by opening the slits of the spectrograph until the optical and electrical resolving powers are just equal, for the particular scanning conditions involved. The optical resolving power[8] of a Littrow prism spectrometer is given by the approximate formula

$$d\tilde{\nu}(\text{cm}^{-})=\frac{\tilde{\nu}^2[1-n^2\sin^2(\alpha/2)]^{\frac{1}{2}}}{8\sin(\alpha/2)(dn/d\lambda)}\frac{S_1+S_2}{f}+F(S)\frac{\tilde{\nu}}{2b(dn/d\lambda)} \tag{3}$$

[8] V. Z. Williams, Rev. Sci. Inst. 19, 135 (1948).

where $n$ = index of refraction of the prism at frequency $\tilde{\nu}$, $\alpha$ is the apex prism angle, $dn/d\lambda$ is the dispersion of the prism material, $S_1$, $S_2$ and $F$ are the slit widths and focal lengths in commensurate units, $b$ is the length of the prism base and $F(S)$ is a function varying from about 0.9 for $S=0$ to 0.5 for $S$ cm$^{-1}=\nu[2b(dn/d\lambda)]$. The second term represents essentially the diffraction limit set by the prism itself, and is generally not more than 20 percent of the first term under our operating conditions so that the resolving power of the instrument will be determined by Eqs. (1a) or (3); whichever is the larger. The current instrument has a $\tau$ of $3\times10^{-5}$ sec. with a PbSe cell and $12\times10^{-5}$ sec. with a PbTe cell (liquid-air cooled). The top scanning speed with the current motor drive is 150 c.p.s., with a scanning time $P$ of 0.002 sec. Under these conditions, a two-micron sweep, i.e., scanning 1–3$\mu$ with the PbSe cell gives us a resolving power of 100 at 3$\mu$ or about 30 cm$^{-1}$. The PbTe cell at 4.25$\mu$, scanning an interval of 1.0 microns under similar conditions has a resolving power of about 75 or about 35 cm$^{-1}$. With the current cells we have a good working signal/noise ratio with slits of 0.15 mm at 3$\mu$ with PbSe and 0.20 mm at 4.25$\mu$ with PbTe. This gives us an optical resolving power of about 25 cm$^{-1}$ at 3$\mu$ and about 15 cm$^{-1}$ at 4.25$\mu$. There-

fore, the resultant limit on resolving power is in fact determined by the time constant of the receiver, and it is useless to attempt to go to finer slits without reducing the scanning rate or scanned interval.

The present instrument was designed primarily for use in emission studies in which the rate of emission varies rather rapidly. In particular, our interests lay in the realm of combustion processes such as explosions in closed chambers. Spectra have been taken quite successfully at rates up to 150 per sec. and typical spectrograms are shown in Figs. 8 and 9. Figure 8 shows the spectrum of a Nernst glower and the absorption spectrogram of the $NH_3$ 3$\mu$ band. Figure 9A shows the sequence of emission spectra of an explosion of $2CO+O_2$ at an initial pressure of one atmosphere in a cylindrical vessel. The viewing was at right angles to the direction of propagation of the flame through a port in the cylindrical wall midway down the tube. For comparison Fig. 9B shows a similar sequence for a different combustible mixture of the same gases. It is evident that the excitation processes for various modes of vibration of the reacting molecules differ markedly, and produce spectra quite suitable for further study. Studies of some of these radiation *vs.* time phenomena will be reported elsewhere in greater detail.

## FUTURE STATUS

While the present instrument has obtained very interesting results and gives promise of considerable usefulness in both emission and absorption studies of a transitory nature, there are obvious lines of improvement. First, one can hope for photo-conducting cells

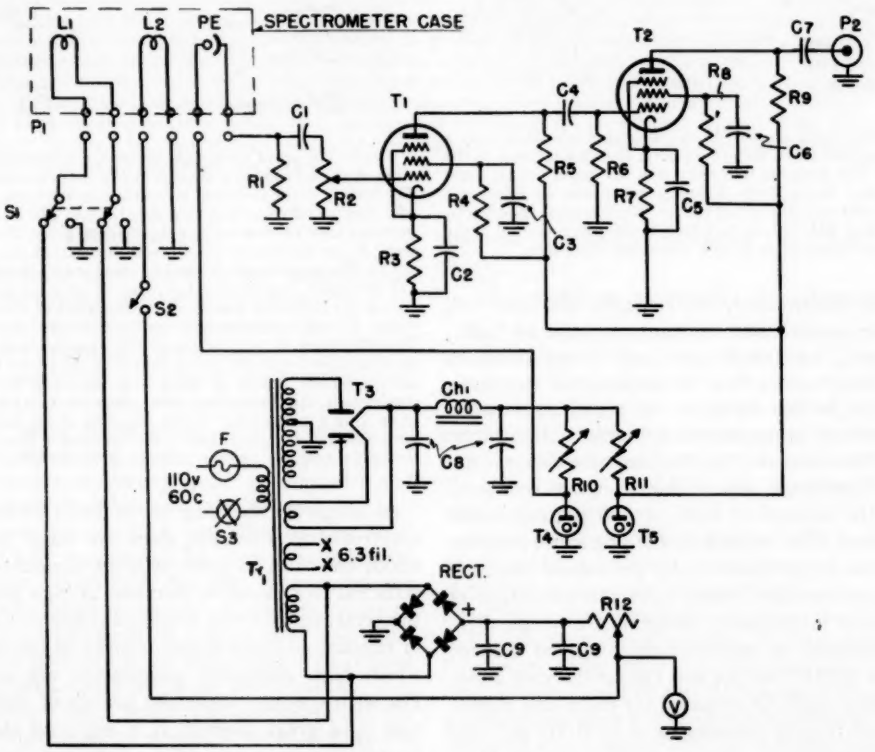


FIG. 7.

| | | | |
|---|---|---|---|
| R1 | 1 meg. 1 w | Tr1 | Stancor P6010 |
| R2, 6 | 250K 1 w | Rect. | F1B1S1B Selectron 5.0 amp. 28 v |
| R3, 7 | 1K 1 w | V | Tripplet 3 in. 1 ma |
| R4, 8 | 200K 1 w | F | 3-amp. fuse |
| R5, 9 | 100K 1 w | Ch | Stancor C-1003, 50 mA |
| R10, 11 | 10K 5 w ww adj. | P1 | 6 circuit connector, cannon |
| R12 | 10K 3 w Pot. | P2 | single circuit connector, cannon |
| C1, 4, 7 | 0.05 microfarad 300 v paper cond. | T1, 2 | 6AU6 |
| C2, 5, 8 | 20 microfarad 50 v electrolytic cond. | T3 | 6X4 |
| C3, 6 | 0.1 microfarad 300 v paper cond. | T4 | 5651 |
| C9 | 2000 microfarad 50 v electrolytic cond. | T5 | OA2 |
| L1 | GE No. 856 straight fil. lamp 4 v 2.5A. | S1 | DPST toggle |
| L2 | 6–8 v Pilot Lamp | S2 | SPST toggle |
| P.E. | 868 photo-cell | S3 | SPST toggle |

Components of this amplifier are not critical since it provides a steady signal, and stability and frequency response are not important.

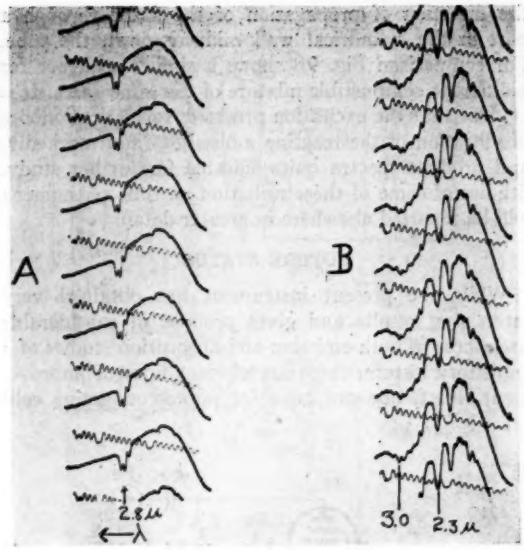


FIG. 8. This figure shows (A) the spectrum obtained with a Nernst glower and shows the atmospheric absorption bands in the 1–3$\mu$ region. The scanning frequency was 125 cycles per sec., and a PbSe cell was the receiver. A fluorite prism was used with slit settings at 0.150 mm. The set of curves (B) illustrates the absorption spectrum of $NH_3$ (10-cm path length, 400-mm pressure) in the same spectral region under similar operating conditions.

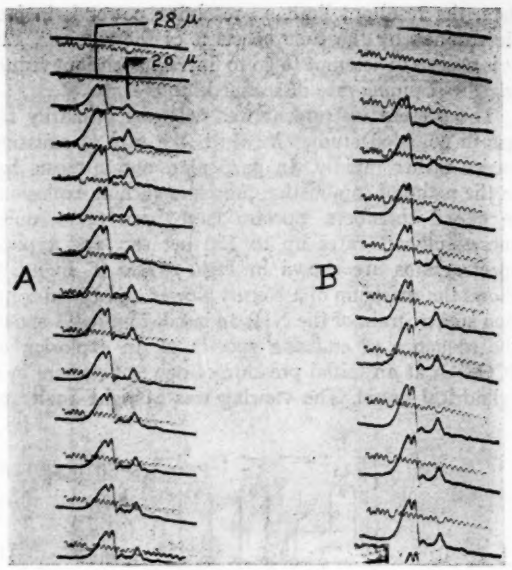


FIG. 9. The set of curves (A) shows the appearance of the spectrum of an explosion of a mixture of $2CO+O_2$, in the region 1–3.5$\mu$. The history of the radiation is recorded for approximately 0.1 sec., with spectra taken at intervals of 1/125 sec. The rise and decay in intensity may be observed for the various bands. The bands at 2.0 and 2.8$\mu$ are attributed to $CO_2$, and the band at 2.3$\mu$ is attributed to CO. The water bands in the 2.7$\mu$ band are also present, since the CO contained five percent hydrogen as an impurity. The set of curves (B) shows the history of the radiation in the same spectral region for an explosion of a combustible mixture of $CO+2O_2$. The differences in rates of rise of the various bands may be seen by comparison with (A) and it is noticed that now the CO bands are completely absent as there is an excess of $O_2$ available for combustion. All explosions took place in a cylinderical vessel 18 in. long 4 in. diameter. Firing occurred at one end, and spectra were observed at right angles to the direction of flame propagation through a sapphire window midway down the tube.

with better performance, for example, the ideal cell would have a short-time constant, perhaps $10^{-5}$ sec., a flatter spectral response curve than is now available, and a resistance lower than the present two megohms, which would further enhance the signal/noise ratio. Second, work is being carried forward on the mirror mount to provide a driving mechanism which will reduce the "deadtime" and enable us more nearly to approach the theoretical limit of 100 percent useful scanning time. With respect to the first item, progress is being made in the use of Golay pneumatic detectors of short time constant, which have the advantage of non-selectivity in frequency reception. Although there is little likelihood at present that $\tau$ can be reduced much below $2\times10^{-4}$ sec. for this type of detector a useful instrument could be obtained for the 6–15$\mu$ region, if one would restrict scanning time to 0.005 sec. and scanning interval to 2$\mu$. The resolving power would be approximately 100 at 8$\mu$, or 12 $cm^{-1}$, and a scanning rate of 60 c.p.s. could be maintained. The equivalent optical resolving power calls for a slit of 0.3 mm in the 8$\mu$ region with a NaCl prism. Very recently Golay[9] has proposed a static multi-slit system which could help solve the problem of restoring by an order of magnitude the sensitivity which is lost in reducing the time constant of the receiver.

Although the resolving power limits are low by usual spectrometric standards, there are many problems for which one-third to one-fourth the normal resolution is sufficient; for example, reactions at high pressures and temperatures give rise to products whose spectra, both in emission and absorption, consist of broad bands for which high resolution instruments are unnecessary. For such spectra, where the history of radical formation is of great interest, it is expected that a video scanning spectrometer will be well worth using.

In addition to its use in the infra-red, we have adapted the instrument for use in the visible and ultraviolet by a simple replacement of the Littrow mirror by a plane grating, and substitution of a photo-multiplier for the photo-conducting element. The use of the grating and the double prism transmission gives usable dispersion, and the $\tau$ of the photo-multiplier is so small that the resolving power is now limited by the optics and by the amplifiers of the oscilloscope. It is planned to so use the instrument in our combustion studies to

[9] M. J. E. Golay, J. Opt. Soc. Am. 40, 257A (1950).

supplement the primary emphasis on infra-red spectroscopy.

### ACKNOWLEDGMENTS

It is a pleasure to express our thanks to F. B. Isakson of the ONR for his services in obtaining for us from the British A. R. L. the photo-conducting cells used in this work as well as for his general interest. Further, we wish to acknowledge our appreciation to B. H. Nall who assisted in the design of the electronic circuits and to J. Sugrue, A. Moore, and K. Dyer whose performance on the shop work left little to be desired.

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# Growth of Silver Filaments and Dendrites*

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Filaments and dendrites of silver have been formed by transfer of silver through a layer of silver halide which has been put in contact with a silver block at about 400°C. According to the scheme proposed for explanation of the observations, silver dissolves in the silver halide and migrates as interstitial ions, transfer occurring because of the existence of a concentration gradient. At the same time vacant anion sites are formed in the reaction at the interface of the block and the silver halide which permit the migration of halide ions toward the silver block. When the rate of silver migration is relatively slow, as with silver bromide or silver chloride, dendrites usually form by migration of silver on the silver already formed. When the silver transfer is fast, as with silver iodide, the migration process does not remove the silver quickly enough and the silver is extruded as long filaments.

## INTRODUCTION

THE growth of silver filaments and dendrites has been the subject of considerable study. As a result, it is well known that such deposits may be produced by many processes, a few examples of which are: thermal decomposition of certain silver compounds, condensation of the vapor, electrolytic deposition, and reduction of silver halide grains in hydrogen or by photographic developers.

The mechanism of photographic development and the formation of hair-silver in the process are particularly interesting and have been discussed by Mott and Gurney[1] and re-examined by Mott.[2] According to the mechanism which they describe, silver is pushed out bodily from the grain because of pressure produced within the grain by the rapid migration of interstitial ions under the influence of the electric field of electrons given to the latent-image speck by the developer.

On the other hand, James[3] has proposed that the filaments are produced by migration of silver from the site of formation (at the triple interface of silver, silver halide, and developer) along the surface of silver previously formed.

The purpose of the present experiments is to attempt to gain further information on the mechanism of filament production from silver halides by a somewhat different experimental procedure from those indicated above.

## DESCRIPTION OF THE BASIC EXPERIMENTS

The experiments require a thin, compact layer of silver halide in intimate contact with a silver block. This layer may be obtained by heating the silver support and melting the silver halide powder which has been placed on it. Then, if the specimen is maintained at a temperature of about 400°C, transfer of the silver from the block through the solid silver halide layer is observed.

Attempts to produce specimens which would give reproducible quantitative measurements of the rate of silver transfer were not successful. Since it was observed that there was reaction only at very few points in the interface, it was supposed that the reaction may be accelerated by impurities. Although only qualitative results were obtained, the rate of silver transfer using a silver iodide layer was obviously much faster than that observed with a silver bromide or silver chloride layer. With a silver iodide layer about 0.2-mm thick, silver was often detected in about ten minutes. On the other hand, several hours were required before the first traces of silver could be seen emerging from a similar layer of silver bromide or silver chloride.

After a large amount of silver had been transferred through the silver iodide layer, bundles of long filaments were found, as in Fig. 1. The length of the filaments shown in Fig. 1 was about one inch. When the transfer was through silver bromide or silver chloride, the silver formed some filaments but more often it

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* Communication No. 1349 from the Kodak Research Laboratories.

[1] N. F. Mott and R. W. Gurney, *Electronic Processes in Ionic Crystals* (Clarendon Press, Oxford, 1940), Chapter VII.

[2] N. F. Mott, Phot. J. 88B, 119 (1948).

[3] T. H. James, J. Chem. Phys. 11, 338 (1943).

flowed out on the surface of the halide, forming dendrites, as shown in Fig. 2.

While there was a flow of silver away from the block, there was a flow of the halide into the block. This was determined by noting, after a considerable transfer of silver, the halide lying at the bottom of deep holes which had been hollowed out in the silver block.

## THE TRANSFER PROCESS

The flow of silver through the halide layers must be assumed to depend upon the existence of some gradient, such as electrical, thermal, or concentration. Since the flow was observed in the absence of applied electrical or thermal fields and counter to the gravitational field, the flow in these experiments has been attributed to concentration gradients in the halide layers.

Although the flow of silver might conceivably be either through the interior or on the surface of the silver halide crystallites, the interior flow seems to give a better explanation of the observed phenomena. If this is the case, then there is little question that the silver is dissociated into interstitial ions and electrons.[4]

The process of silver solution and flow in the silver halide is apparently the same as that observed in the oxidation of a metal such as copper.[5] Evidence of the solution of silver in silver bromide is the observation that silver bromide specimens which had been in contact with silver at high temperature colored much more rapidly, owing to photolysis, than specimens similarly treated but in contact with glass. It is well known that such darkening is greatly accelerated when excess silver atoms are present. Warfield[6] suggests that, in his experiments on conductivity in silver chloride induced by electron bombardment, the greater trap density near the surface of the silver chloride may be explained by the solution in the silver chloride of the surface silver film used as an electrode.

In addition to the excess of silver ions and electrons which is established in the halide at the interface, a concentration gradient of vacant anion sites must be produced, giving a flow of halide into the block. The large diameter of the halide ion prevents its movement in interstitial positions.

To explain the growth of long filaments or dendrites it is assumed that the concentration gradients persist even though there is silver on both sides of the silver halide layer. The coverage of the surface from which the silver emerges is not nearly as complete as at the interface with the silver block. For this reason, the quantity of silver redissolving after filament or dendrite formation cannot be as large as that dissolving from the silver block. Another factor which is probably important in slowing the counterreaction is the lack of impurities in the silver threads of abundance greater than about one part in 50,000.

The greater rate of silver transfer in silver iodide is probably related to the higher silver-ion mobility in silver iodide than in silver bromide or silver chloride and suggests that the rate-limiting factor in the transfer process is this ionic mobility. In silver iodide very high ionic mobility exists because of the peculiar crystal structure above 146°C, in which the silver ions are distributed among many possible sites separated by rather small potential barriers.[7] The similarity of structures of silver iodide and silver sulfide[8] at high temperatures suggests that silver filaments might also be grown rapidly using silver sulfide as the conducting layer. It was found, indeed, that silver was transported through silver sulfide much more rapidly than through silver bromide or silver chloride, and filament formation resulted.†

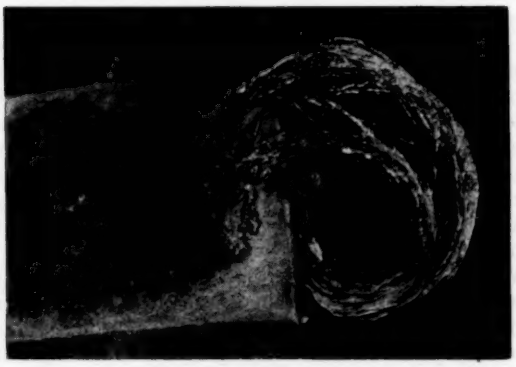

FIG. 1. Bundles of silver filaments about an inch long, grown through a silver iodide layer.

## DESCRIPTION OF SILVER FORMATIONS

The growth of relatively long straight filaments through the iodide and sulfide layers afforded specimens which could be conveniently studied using the x-ray diffraction technique. Diffraction patterns were taken in such a way that preferred orientation along the filament axis would be easily recognized, but no preferred orientation of any kind was observed. The diffraction rings were very spotty, and an estimate of 25$\mu$ for the crystal size was obtained. This would indicate that a single filament may contain roughly 100 crystallites in its diameter. This is consistent with the observation by microscope that what appears to be a single thread in the relatively low magnification of Fig. 1 is actually composed of many smaller filaments.

Bundles of filaments up to one inch in length were

[4] J. H. Simpson, Proc. Roy. Soc. **197**, 269 (1949).
[5] Reference 1, Chapter VIII.
[6] G. Warfield, "A study of electron bombardment induced conductivity in silver chloride single crystals," Thesis, Cornell University (1950), p. 55
[7] L. W. Strock, Zeits. f. physik. Chemie **25B**, 441 (1934).
[8] P. Rahlfs, Zeits. f. physik. Chemie **31B**, 157 (1936).
† A description of silver filament production from silver sulfide in contact with silver at high temperature has been given by W. Ostwald, Kolloid Zeits. **102**, 35 (1943).

grown from silver iodide. In general, the diameter of a filament was nearly uniform along its entire length. In some cases, however, filaments were found which had narrowed and finally stopped growing completely.

There seems to be no question that the long silver filaments are formed by squeezing out, owing to pressure within the silver halide crystals. On the other hand, the dendritic silver formations usually observed on silver bromide or silver chloride must be due to flow of silver over the material already deposited. Whether silver is formed by extrusion or surface migration is apparently dependent upon the rate of silver transport.‡ If the transport is sufficiently slow, the mobility of the silver will permit its removal from the site of formation. On the other hand, transport which is so rapid that the silver cannot remove itself from the path by migration causes extrusion to occur.

In the case of very rapid transport observed for a silver iodide layer, the rate of filament growth was about 1 cm in 24 hours. This amounts to about $\frac{1}{10}$ micron per second and is not very different from the value Mott[2] calculated as the rate of filament extrusion which may occur in development of a silver bromide grain, according to the Gurney-Mott[1] mechanism. Mott found a value of 1/100 micron per second as a lower limit of the rate at which silver is pushed out, and the implication is that this is sufficient for the formation of extruded filaments. If, in the development process, silver does migrate through the grain at the rate given by Mott, the present experiments indicate that extrusion of threads will occur.

FIG. 2. Silver dendrites spreading over silver bromide surface about 4 millimeters from the point of origin.

The correlation of the silver transport and growth phenomena in the present experiments with the phenomena occurring in the development process cannot be stated with certainty. It does seem likely, however, that there is considerable similarity and it may be that the only essential difference is the nature of the force which causes the silver ions to move: in the present case, a thermally activated migration giving a net flow because of a concentration gradient; and in development, an ionic drift in the electrical field produced by electrons of the developer.

‡ In a private communication, G. I. P. Levenson has stated similar conclusions on the basis of observations of the development of silver bromide grains at different rates.

## Society for Applied Spectroscopy

The October meeting of the Society for Applied Spectroscopy will be held October 3, 1950. There will be an informal dinner at Tosca's, 118 Fulton Street, New York at 6:00 P.M. The regular meeting will be held at Socony-Vacuum Training Center, 63 Park Row, New York at 8:00 P.M. and the speaker, Dr. Bruce Billings of Baird Associates, Inc. will discuss "Right and Left in Optics."

# Estimation of Ionization Potentials by Comparison with Neighboring Elements

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(Received June 14, 1950)

If a spectrum contains an unperturbed series of at least three members, the ionization potential can be found with fair accuracy from its limit. If but two members are available, serious errors occur if the Ritz correction is ignored. This correction can often be closely estimated by comparison with elements of neighboring atomic numbers. This method is familiar, but published estimates have not been made on a uniform system. Such estimates for spark spectra from Ca II to Zn II give ionization potentials differing from a smooth formula by ±0.02 volt, while the differences in the three cases where the Ritz correction was not applied, average ±0.39 volt.

THE analyses of the spectra of an element in successive stages of ionization fix with great precision the relative energy levels in each stage. Connection of those in one and the next demands the determination of the limit of a series. One accurate limit locates all the levels of the second relative to those of the first and determines the ionization potential, even though this may correspond to the limit of some other series, or to a double electron jump.

An unperturbed series of at least four members gives a value of its limit reliable to a few $cm^{-1}$, or better, when an extended Ritz formula is used:

$$T_n=\frac{N^2R}{(n+\mu+\alpha T_n+\beta T_n^2)^2},$$

where $T_n$ is the term-value and $N-1$ the degree of ionization. A remarkably simple method of calculation is given by Shenstone.[1] If but three consecutive members are known, one may set $\beta=0$ and obtain a good approximation. But when only two members are available, the assumption that $\alpha=0$ (that is, of a simple Rydberg formula) leads to serious errors—which, since $\alpha$ is almost always positive, make the calculated limit and ionization potential come out too high.

This error may be greatly reduced by comparison of the series constants with those for elements of neighboring atomic numbers. If $x_n$ is the fractional part of the denominator

$$x_1-x_2=(T_1-T_2)\{\alpha+\beta(T_1+T_2)\}.$$

Now, for an electron of the same type, $\alpha$ and $\beta$, and consequently $x_1-x_2$, vary smoothly with the atomic number, and values can be estimated for intervening elements if well-determined ones are not too far apart. This method has been familiar for more than twenty years, and has been used to find ionization potentials for almost all the elements in which series of only two members are available. The methods of estimation of $x_1-x_2$ for different elements varied considerably in the early work and it appears worth while to discuss some results of a uniform treatment.

This method is properly applicable only when the "running" electron of the series is "external" and not part of a shell in process of formation, and only spectra corresponding to successive steps in the formation of such a shell are comparable.

It is most useful in the "iron group" (and its homologs) where sequences of eleven spectra, with shells of 0 to 10 *d*-electrons added to the same base, exist.

If $n$ is the number of electrons outside the argon shell in the neutral atom, there is one such sequence, $3d^{n-2}\ ms$ in the second spectra, and two in the first, $3d^{n-1}\ ms$ and $3d^{n-2}\ 4s\ ms$. (Though $3d^{n-2}\ 4s^2$ does not properly belong to the last series, the values of $x_1-x_2$ between this and $3d^{n-2}\ 4s\ 5s$ may often be used.)

A considerable obstacle in practice arises from perturbations of the terms of a given series by neighboring terms. For example, the addition of a *p* electron usually produces two triads of terms of multiplicity differing by 2, which may be perturbed by members of triads from other limits, and by one another. When the limit is an *S* term, each electron gives only two series and longer and less perturbed series are often observed.

These complications are worse in arc than in spark spectra—at least in the iron group—since the number of possible perturbing terms is greater.

The second spectra of the elements of this group form therefore a good example. The series arising from the addition of *s* electrons to the lowest level of the third spectrum are best known and least likely to be perturbed. Among the eleven spectra to be considered, series of more than two members have been observed in only four—Ca II, Mn II, Cu II, and Zn II. In three of these the limit is an *S* term; for Cu II Shenstone's unusually complete analysis is available. Series of two members are known in all the rest except V II, in which no terms arising from 5*s* were found, despite a thorough analysis—some other laboratory source being doubtless required for their production.

The calculations here described are based on the data given in Vol. I of *Atomic Energy Levels* and additional material prepared for Vol. II and generously furnished by Mrs. Sitterly. The essential elements are given in Table I. The first column contains the absolute value $L$ of the ground state of each second spectrum (II) referred to the ground state of the third spectrum (III). The terms of lower multiplicity have as limit the next component of this ground term in the third spectrum, which is higher by $\delta L$.

The second column gives the types and energy levels

[1] A. G. Shenstone, Phil. Trans. Roy. Soc. London **A235**, 199 (1936).

TABLE I.

| Spectrum L / δL | | Level | $x_2-x_1$ | Final ΔL | Final $x_2-x_1$ | Diff. D | Mean M |
|---|---|---|---|---|---|---|---|
| Ca II | $^1S_{\frac{1}{2}}$ | 0 | | 0 | | | |
| 95748 | | 52167 | +0.0326 | | +0.0326 | +0.0000 | +0.0326 |
| Sc II | $^3D_1$ | 0 | | −760 | | | |
| 104000 | | 57551 | +0.0197 | | +0.0376 | +0.0065 | +0.0344 |
| +197 | $^1D_2$ | 2541 | | | | | |
| | | 58252 | +0.0130 | | +0.0311 | | |
| Ti II | $^4F_{1\frac{1}{2}}$ | 0 | | −494 | | | |
| 110000 | | 62180 | +0.0321 | | +0.0434 | +0.0155 | +0.0356 |
| +184 | $^2F_{2\frac{1}{2}}$ | 4629 | | | | | |
| | | 63168 | +0.0163 | | +0.0279 | | |
| V II | $^5F_1$ | 2605 | | [+3600] | | | |
| 114600 | | — | | | | | |
| +145 | $^3F_2$ | 8640 | | | | | |
| | | — | | | | | |
| Cr II | $^6D_{\frac{1}{2}}$ | 11962 | | −2940 | | | |
| 136000 | | 82692 | −0.0117 | | +0.0482 | +0.0183 | +0.0390 |
| +60 | $^4D_{\frac{1}{2}}$ | 19528 | | | | | |
| | | 84208 | −0.0314 | | +0.0299 | | |
| Mn II | $^7S_3$ | 0 | | 0 | | | |
| 126147 | | 74560 | +0.0516 | | +0.0516 | +0.0216 | +0.0408 |
| 0 | $^5S_2$ | 9473 | | | | | |
| | | 76375 | +0.0300 | | +0.0300 | | |
| Fe II | $^6D_{4\frac{1}{2}}$ | 0 | | −454 | | | |
| 130978 | | 77861 | +0.0441 | | +0.0533 | +0.0237 | +0.0414 |
| +436 | $^4D_{3\frac{1}{2}}$ | 7955 | | | | | |
| | | 79439 | +0.0204 | | +0.0296 | | |
| Co II | $^5F_5$ | 3350 | | +422 | | | |
| 137150 | | 84012 | +0.0629 | | +0.0543 | +0.0223 | +0.0432 |
| +841 | $^3F_4$ | 9813 | | | | | |
| | | 85479 | +0.0406 | | +0.0320 | | |
| Ni II | $^4F_{4\frac{1}{2}}$ | 8394 | | −2792 | | | |
| 149200 | | 91798 | −0.0003 | | +0.0518 | +0.0156 | +0.0440 |
| +1361 | $^2F_{3\frac{1}{2}}$ | 13550 | | | | | |
| | | 93526 | −0.0158 | | +0.0362 | | |
| Cu II | $^3D_3$ | 21929 | | 0 | | | |
| 163666 | | 108015 | +0.0487 | | +0.0487 | +0.0073 | +0.0450 |
| +2072 | $^1D_2$ | 26265 | | | | | |
| | | 110366 | +0.0414 | | +0.0414 | | |
| Zn II | $^2S_{\frac{1}{2}}$ | 0 | | 0 | | | |
| 144891 | | | | | | | |
| 0 | | 88437 | +0.0478 | | +0.0478 | 0.0000 | +0.0478 |

of the lowest components of the series terms—the upper entry of each pair corresponding to $4s$ and the lower entry to $5s$. Subtracting these, according to the multiplicity, from $L$ or $L+\delta L$, the term values and denominators are found and so the differences $x_2-x_1$. For example, in Fe II, $L+\delta L=131414$. Subtracting the given $^4D_{3\frac{1}{2}}$ levels from this gives term-values 123459 for $4s$, and 51975 for $5s$. The corresponding denominators are 1.8856 and 2.9060, whence $x_2-x_1=+0.0204$.

The differences $D$ of the computed values of $x_2-x_1$ for the two multiplicities in a given spectrum are almost independent of the assumed series limit. These run smoothly—indicating that perturbations are small. The means $M$ of the two, which are sensitive to the adopted limit, are ragged. The well-determined values (Ca, Mn, Cu, Zn), however, are represented by $M=0.0401+0.00145(Z-25)$ with a maximum residual of 0.0009. By trial and error, it is easy to find the corrections $\Delta L$ to each assumed limit which will make the resulting values of $M$ agree with this empirical formula.

TABLE II. Second ionization potentials for the iron group.

| Sp | Ionization energy cm⁻¹ | Ionization energy Volts[a] | Series limit volts | O−C | Old I.P. | Corr. |
|---|---|---|---|---|---|---|
| Ca II | 95748 | 11.87 | 11.87 | +0.02 | 11.87 | 0.00 |
| Sc II | 103240 | 12.80 | 12.80 | +0.03 | 12.89 | −0.09 |
| Ti II | 109506 | 13.57 | 13.57 | −0.03 | 13.63 | −0.06 |
| V II | (118200) | (14.65) | (14.33) | (−0.01) | 14.2 | (+0.45) |
| Cr II | 133060 | 16.49 | 15.01 | −0.01 | 16.86 | −0.37) |
| Mn II | 126147 | 15.64 | 15.64 | +0.01 | 15.64 | 0.00 |
| Fe II | 130524 | 16.18 | 16.18 | −0.00 | 16.23 | −0.05 |
| Co II | 137572 | 17.05 | 16.64 | −0.03 | 17.0 | +0.05 |
| Ni II | 146408 | 18.15 | 17.11 | −0.02 | 18.5 | −0.35 |
| Cu II | 163666 | 20.29 | 17.57 | +0.02 | 20.29 | 0.00 |
| Zn II | 144891 | 17.96 | 17.96 | +0.01 | 17.96 | 0.00 |

[a] The factor of proportionality is taken as 0.00012395.

These are given in the fourth column of Table I and followed by the resulting values of $x_2-x_1$, $D$, and $M$. The resulting values of $L+\Delta L$ give a system of ionization potentials which have been consistently, though empirically, adjusted.

These appear in Table II. The second and third columns give the adopted energy difference between the ground limits in the second and third spectrum, in $cm^{-1}$ and volts, and the fourth that between the lowest term $3d^{n-2}\ 4s$ and its limit. The next column gives the residual of this from the empirical expression $11.850+0.610\ (Z\text{-}20)+0.029\ (Z\text{-}20)\ (30\text{-}Z)+0.0013\ (Z\text{-}20)\ (25\text{-}Z)\ (30\text{-}Z)$. These residuals are remarkably small, run smoothly, and indicate again that the perturbations are probably small.

From the run of these residuals it has been estimated that the missing value for V II is not far from −0.01, which leads to the energy levels given in parentheses.

The last two columns of the table give the values of the I.P. taken from the literature, and the corrections resulting from the present work.

The four values depending on long series were left unaltered. In the four cases where a previous attempt was made to apply a Ritz correction the change averages ±0.06 volt—probably significant, but of no serious astrophysical importance. Where no such attempt was made, the corrections average ±0.39 volt. The two uncorrected Rydberg series give results much too high, while the rough estimate for V II was too low. The present results indicate that, under the most favorable conditions, careful estimates of the Ritz correction give values for the ionization potential correct within a fraction of one percent. It would be of great interest to check this conclusion, and obtain really reliable values, by the discovery of further series members. It may well require specially designed light-sources to provide the required lines with measurable intensity.

This communication presents an example of the method—not a complete survey of its applications. Series involving three or more $s$-electrons are known in the arc spectra of nine of the twelve elements of the iron group—excepting Sc I, V I, and Co I. The data for the homologous elements Rb to Cd are still incomplete.

Hearty thanks are due to Mrs. Sitterly for her kindness in checking the numerical data.

# Book Reviews

**Elementary Photography** (Second Edition). GILFORD G. QUARLES. McGraw-Hill Book Company, New York, 1948. 345 pp.+xii. Price $4.50.

A strictly elementary text for the amateur photographer and for the non-photographically trained scientist who may wish to improve his photographic techniques. Considerable "trade" know-how and technique information are supplied in the discussion which may be useful in technical or visual photography, although much of the text is directed towards the pictorial artist and his needs. The discussion on development technique, choice and testing of equipment, preparation of prints, copying and lantern slides, and the re-processing by reduction, intensification and other treatments may serve to provide the optical research worker with helpful suggestions in the improvement of photographic technique applications to his problems.

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**Optique Physiologique: Volume II. Lumière et Couleurs.** YVES LE GRAND. Editions de la Revue d'Optique, Paris, 1948. 490 pp. Price 1600 fr.

The second volume of *Optique Physiologique* has recently been published by the editors of the Revue d'Optique. The author, Yves Le Grand, is Professor of the National Museum of Natural History and Examiner of the Students of the Polytechnic School of Paris.

The first volume by the same author and publisher appeared in 1946 and was entitled *The Dioptrics of the Eye and Its Correction.* It treated the eye as an optical apparatus, designed to form the image of outside objects by simple refraction of the light when passing through the many transparent media of different indices of the eye. In the case of good vision the image was sharp and formed on the retina. If the image was not formed on the retina, the lenses necessary to produce good vision were determined. The book was written primarily for the refractionist, who determines the necessary correction of the visual defects and who is also interested in both monocular and binocular movements of the eyes.

The approach in the present volume is quite different. The eye is considered as the receptor of radiant energy, and a study is made of the response of the retina when certain wave-lengths are absorbed. Consideration is given to the transformation of radiant energy into nervous energy, and the effect of the energy on the visual centers and the brain as it is recognized as light and color. This volume is prepared from the point of view of the physician and emphasis is given to the physical aspects of the problem, although it is not intended to ignore the physiologic aspects. Section A of the present volume deals with the experimental aspects of the physics of the eye, while Section B deals with the anatomy, physiology, and psychology necessary to understand the theories of vision.

It is planned in a third volume to attempt to synthesize the points of view presented in the first two volumes and to present the essential laws which govern our vision of the universe. It will include the topics form, detail, relief, and movements.

The reviewer feels that Volume II of *Optique Physiologique* is very complete, comprehensive and up-to-date. There is a very adequate bibliography at the end of the book and also a section of problems, based upon the material presented in the different chapters, with their solutions.

Books on Physiological Optics in general have the weakness that they tend to present either the physics, physiology, or psychology of vision, with emphasis on the field in which the author has been working and a rather sketchy treatment of the other phases of vision. Your reviewer feels that Yves Le Grand has done an excellent job of presenting the different aspects of vision with equal emphasis, and he highly recommends Volumes I and II to workers in the field of Physiological Optics, with the suggestion that they acquire Volume III when it appears, on the assumption that it will be equally good.

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**Quantitative Ultramicroanalysis.** PAUL L. KIRK. John Wiley and Sons, Inc., New York, 1950. 310 pp.+vii. Price $5.00.

The atomic energy project has brought with it tremendous installations and techniques of processing and extracting enormous quantities of material; but it has also developed a new school of technical workers who are concerned with the handling and analysis of minute quantities of materials. This ultramicro technique is sometimes required by the minute quantities of material available and at other times by the toxic or radioactive properties of the material which necessitates the extremely small samples. The techniques developed may serve to advantage in the study of biological and trace materials as well as in the field of radioactive substances. The new classification of ultramicro-, combined with the micro- and macromethods now in use increases the range of analytical techniques and sources of information.

Of particular interest to the worker in the field of optics are the chapters on the theory of microcolorimetry, spectrophotometric methods as well as the discussion on manipulation and analysis of the ultramicro samples. In the application of spectrophotometric methods consideration is also given to submicrogram methods. For an approximate definition of analytical sample size and method the following table may serve as a guide.

| Method | Sample Size |
|---|---|
| Macromethod | $10^{-1}$ g = 100 mg |
| Semimicromethod | $10^{-2}$ g = 10 mg |
| Micromethod | $10^{-3}$ g = 1 mg |
| Ultramicromethod | $10^{-6}$ g = 0.001 mg = 1$\gamma$ = 1 microgram |
| Submicrogrammethod | $10^{-9}$ g = 0.001$\gamma$ = 1m$\gamma$. |

Procedures are given for the determination of iron, copper, manganese, iodine and some representative organic compounds in concentrations of 5 to 50 m$\gamma$ through the use of spectrophotometric methods and the employment of special cells and techniques.

This book should serve as a useful reference for the micro technician as well as advising other workers as to the analytical and manipulation proficiency which might be expected in working with minute quantities of material.

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# Letters to the Editor

## On Sensitive Color

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June 5, 1950

THE color produced by placing a thin plate of crystal between Nicol prisms may be treated in the same manner as the interference color produced by a thin layer on glass, as described in the previous paper.[1] An extended study of this phenomenon gives us an interesting result concerning the "sensitive color."

In Fig. 1, let $X$ and $Y$ be the planes of polarization of light in the crystal, $P$ and $A$ those of polarizer and analyzer respectively. Taking the angle between them as shown in Fig. 1, the intensity of light coming out from the analyzer is, for unit value of incident light:

$$I=\cos^2(\rho-\theta)-\sin 2\rho\cdot\sin 2\theta\cdot\sin^2(\delta/2).$$

where $\delta=(2\pi/\lambda)\mu d$, $d$ being the thickness of the crystal plate, and $\mu$ the difference of refractive indices in the crystal, so $\mu d$ is the phase retardation during passage of the light through the crystal.

Now we shall consider the following special cases:

(a) When $\rho-\theta=\pi/2$, then

$$I=\sin^2 2\theta\cdot\sin^2(\delta/2).$$

(b) When $\rho+\theta=\pi/2$, then

$$I=\sin^2 2\theta\cdot\cos^2(\delta/2).$$

Case (a) is that of crossed Nicols. Parallel Nicols and crystal set in diagonal position ($\rho=\theta=\pi/4$) is a special case of (b).*

On the other hand, the intensity of light reflected from a thin layer with thickness $d$ and refractive index $n$, coated on glass with refractive index $n_g$, is also given by $\sin^2(\delta/2)$ or $\cos^2(\delta/2)$—where $\delta=(4\pi/\lambda)nd$—according as $n_g=1$ or $n_g=n^2$. So the interference color of case (a) corresponds to the former and case (b) to the latter. Accordingly, the color sensitivity—the rate of change of color with the variation of retardation—can be calculated by the method described in the former paper. The author has calculated it in case (b) anew, using MacAdam's U.C.S. and C-light source, and plotted the results in Fig. 2 together with that of case (a), which was already given in Fig. 6 of the former paper.

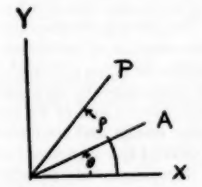


FIG. 1. $X$, $Y$: planes of polarization in crystal; $P$, $A$: planes of polarization in polarizer and analyzer.

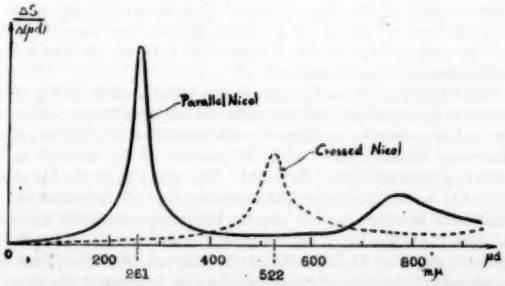


FIG. 2. Color sensitivity.

The interference color in the neighborhood of the peaks of the curves is purple for both cases, which conforms with the well-known sensitive purple, but we find a more important fact that the sensitive color in case (b) is far more sensitive than in case (a). This fact has not, so far as the author knows, ever been noticed by previous authors.[2] So the most sensitive purple is not produced by the crystal whose retardation is 522 mμ between crossed Nicol prisms,† but by the crystal of retardation 261 mμ placed in diagonal position between parallel Nicol prisms, or more generally speaking, in the position $\rho+\theta=\pi/2$. But if the crystal is not placed in the diagonal position, the color becomes dull and sensitivity is lowered. Calculations show that if the deviation from the diagonal position exceeds 5°, the sensitivity becomes smaller than with crossed Nicol prisms.

[1] H. Kubota, J. Opt. Soc. Am. **40**, 146 (1950).
[2] E. Lommel, Ann. d. Physik Chemie **43**, 473 (1891); A. Wenzel, Physik. Zeits. **18**, 472 (1917).
* In the previous paper, the author has erroneously written $\cos^2\delta$, this must be written as $\cos^2(\delta/2)$.
† The usually stated value is about 575 mμ (e.g., E. A. Wülfing, Sitzungsberichte der Heidelberg Akad. der Wiss. **24**, 1 (1910). But according to Fig. 2, this must be 522 mμ if the C-light source is used and the dispersion is neglected.

## On a Method for the Calibration of Photographic Emulsions

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February 20, 1950

IN the present paper a method is described for the calibration of photographic plates in which only the light intensity is changed, the exposure time being kept constant and so chosen as to be equal to the exposure time of the plate under consideration. The calibration marks are obtained one by one and therefore may be made of adequate dimensions for a precise measurement of the densities (height: 5 mm). The proposed method is based on the variation of the light output of an electric incandescent lamp with its voltage as a means of obtaining variable exposures for the calibration marks. This method was suggested but apparently not tried by Sawyer.[1] The lamp employed for this purpose is a tungsten filament one, rated at 10 v and 7.5A. Its voltage is determined with an error less than 0.1 percent by means of a potentiometer. The light output, after passing through a monochromator and falling on a vacuum photo-cell, is measured by the potential drop produced by the photo-current on a high value resistor. This potential drop is measured with a precision potentiometer, using an electrometric amplifier as a zero instrument.[2,3] In this way, the light intensity is measured in arbitrary units with a precision that varies between 0.1 and 1 percent. A calibration curve of the lamp, obtained in this form for a wave-length of 6000A, shows a second-degree curve (on logarithmic scale), that differs little from a straight line of equation: $\log I=3.5\log V+C$.

In order to avoid stray light inside the spectrograph an illuminating system was used that determines and maintains the input solid angle into the collimator invariable. The device consists fundamentally of a diffuser in front of an adjustable iris diaphragm, and a lens adjacent to the spectrograph slit, that forms an image of the iris diaphragm on the collimator lens.

All the calibration methods in which the intensity is varied, habitually consist of some means by which one diminishes the light flux of a source of constant intensity $I_0$ by a known factor $k$ (i.e., filter factor) and the curve is plotted with this factor as independent variable. In general terms: $I=kI_0(0\leq k\leq 1)$.

Two criteria have been proposed as a test for a given calibration technique and as a means to make systematic errors evident: The

self-consistency test and the comparison with the inverse square law.[4,5] In the self-consistency test, one determines two characteristic curves: one with a value $I_0$ of the intensity of the light source and the other with a value $I_0'=AI_0$. In the first case one obtains:

$$d=f(It^p)=\varphi(\log I+p\log t). \quad (1)$$

Because $t=t_0=$constant, Eq. (1) becomes

$$d=\varphi(\log k+\log I_0+p\log t_0)=\varphi(\log k+C), \quad (1a)$$

and in the second case:

$$d'=\varphi(\log k+\log I_0'+p\log t_0)=\varphi(\log k+\log A+C'). \quad (2)$$

The two curves obtained are equal and displaced horizontally by an amount equal to $\log A$ if, and only if the values of the relative intensities of radiant energy incident on the emulsion are given actually by the values of $k$.

The self-consistency test gives an indication of the correctness of the technique employed, but does not reveal any errors due to the principles of the technique, since this test is fulfilled as well when using $I$ as independent variable as when using $t$. The $t$ variation method gives habitually no self-consistent results because $p$ is not actually a constant.

To make sure that the calibration method used consists actually of a variation of $I$, a comparison with a standard is necessary. The inverse square law method is used as a standard in such conditions as to fulfill the self-consistency test.[6] The self-consistency and the inverse square law tests are two necessary and sufficient conditions that all good calibration techniques should fulfill. They are not sufficient when taken separately.

Using the described illumination system of the spectrograph, the results obtained with the variable voltage incandescent lamp method on Eastman I-F and III-F emulsions, were self-consistent and coincident with the inverse square law method.

* This paper is written from a part of the authors' doctoral thesis and was presented at the 12th meeting of the Argentine Association of Physics, September 21, 1948.

[1] R. A. Sawyer, *Experimental Spectroscopy* (Prentice-Hall, Inc., New York, 1944), p. 258.
[2] L. A. DuBridge, Phys. Rev. **37**, 392 (1931).
[3] C. E. Nielsen, Rev. Sci. Inst. **18**, 18 (1947).
[4] Grossman, Sawyer, and Vincent, J. Opt. Soc. Am. **33**, 185 (1943).
[5] G. R. Harrison, J. Opt. Soc. Am. **18**, 492 (1929).
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## On the Fluorescence and Phosphorescence Emission Spectra of Manganese-Activated Zinc Silicate

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August 3, 1950

IN a recent paper[1] we reported measurements of the fluorescence and phosphorescence emission spectra of a $Zn_2SiO_4$:Mn phosphor. These measurements showed that the emission spectrum at 3 to 25 milliseconds after cessation of excitation is the same as that observed in fluorescence. This was taken to be evidence against the existence of "sub-bands" in the emission spectrum of $Zn_2SiO_4$:Mn. While our paper was in press a note by Nagy[2] appeared, reporting a different result of essentially the same experiment. Nagy finds that the yellow component, which gives the $Zn_2SiO_4$:Mn fluorescence spectrum its asymmetric appearance, is absent from the phosphorescence spectrum 3 milliseconds after cessation of excitation. He concludes that his result justifies the analysis of the $Zn_2SiO_4$:Mn fluorescence emission spectrum into a number of Gaussian "sub-bands."

Because of this direct conflict of experimental results we have carefully repeated and extended our earlier measurements. The experimental arrangement was the same as that previously used.[1,3] The lamp was a 4-watt, low pressure, mercury lamp fitted with a Corning 9863 filter and operated on d.c. The phosphoroscope disk was rotated at 1900 r.p.m., its speed being checked with a strobotac. The phosphor was viewed by a Bausch and Lomb single glass prism monochromator, a 1P21 photo-multiplier being the detector. The photo-multiplier output was amplified by a d.c. amplifier and recorded on an Esterline-Angus 5-milliampere recorder. A complete run could be taken in one minute. For most of the runs slit widths were used corresponding to a band pass of 100A at 5461A. For one of the phosphors the work was repeated with slit widths corresponding to a 25A band pass at 5461A.

TABLE I. Emission spectra of $Zn_2SiO_4$:Mn(Mn/Zn=0.71).†

| | Phosphorescence Emission 4 millisec decay | | | Fluorescence Emission Rotating disk | | | Fluorescence Emission Stationary disk | |
|---|---|---|---|---|---|---|---|---|
| λ | #1 | #2 | #3 | #1 | #2 | #3 | #1 | #2 |
| 4700 | 0 | 0 | 0 | .1 | 0 | .1 | .1 | .1 |
| 50 | .3 | .3 | .4 | .3 | .3 | .3 | .3 | .2 |
| 4800 | .7 | .7 | .8 | .7 | .7 | .7 | .8 | .8 |
| 50 | 2.0 | 2.0 | 2.2 | 2.0 | 2.0 | 2.1 | 2.0 | 2.1 |
| 4900 | 5.4 | 5.6 | 5.5* | 5.0 | 5.4 | 5.3 | 5.8 | 5.3 |
| 50 | 11.8 | 12.1* | | 12.1* | 12.1* | 12.1* | 12.3* | 12.6 |
| 5000 | 24.0* | | 23.4 | | 21.1 | 21.3 | | 24.4* |
| 50 | 41.7 | 42.8 | 41.8 | 38.0 | 38.8 | 38.1 | 41.5 | 41.3 |
| 5100 | 62.5 | 62.3 | 62.3 | 58.5 | 57.8 | 59.0 | 62.7 | 61.7 |
| 50 | 85.3 | 84.1 | 85.1 | 82.0 | 80.8 | 80.8 | 84.8 | 84.8 |
| 5200 | 98.5 | 98.0 | 98.5 | 98.0 | 97.4 | 98.0 | 98.8 | 99.1 |
| 30 | 100. | 100. | 100. | 100. | 100. | 100. | 100. | 100. |
| 50 | 99.0 | 98.5 | 99.3 | 99.2 | 98.6 | 98.0 | 98.6 | 97.7 |
| 5300 | 91.4 | 90.8 | 91.2 | 91.2 | 91.1 | 90.6 | 91.0 | 89.6 |
| 50 | 77.5 | 78.1 | 77.3 | 76.5 | 76.7 | 76.5 | 77.8 | 77.3 |
| 5400 | 62.4 | 62.5 | 62.1 | 61.6 | 61.6 | 61.0 | 62.0 | 63.7 |
| 50 | 50.0 | 50.2 | 51.0 | 49.0 | 48.3 | 48.4 | 49.0 | 50.4 |
| 5500 | 39.8 | 39.2 | 39.1 | 38.1 | 37.9 | 38.3 | 41.2 | 39.3 |
| 50 | | | | 28.8 | 28.6 | 28.5 | | 30.6 |
| 5600 | 24.2* | 23.5* | 23.8* | 21.1 | 21.1 | 20.7 | 24.4* | |
| 50 | 18.0 | 17.5 | 17.5 | | | | 18.1 | 17.6* |
| 5700 | 13.2 | 12.7 | 12.9 | 13.5* | 13.6* | 13.3* | 12.8 | 12.7 |
| 50 | 9.7 | 9.5 | 9.3 | 9.8 | 9.9 | 9.8 | 9.5 | 9.4 |
| 5800 | 7.2 | 6.8 | 7.0 | 7.5 | 7.2 | 7.2 | 6.8 | 6.9 |
| 50 | 4.9 | 4.8 | 4.8 | 5.2 | 5.0 | 5.0 | 4.8 | 4.7 |
| 5900 | 3.4 | 3.1 | 3.2 | 3.5 | 3.4 | 3.2 | 3.2 | 3.0 |
| 50 | 2.1 | 2.1 | 2.0 | 2.2 | 2.1 | 2.1 | 1.9 | 2.1 |
| 6000 | | | | 1.4 | 1.4 | 1.4 | 1.2 | 1.3 |

† Data are the observed photo-cell response converted to 100 at the peak, but not corrected to true spectral energy. Gaps in data are where the amplifier sensitivity was changed during the run making it impossible to get a reading at these points. Numbers marked with an asterisk represent data taken with the recorder pen deflecting rapidly (last point before or first point after amplifier sensitivity change), and hence may be less accurate than the rest of the data.

The fluorescence spectra were examined in two ways: first, with the disk spinning, so that excitation was intermittent as in the phosphorescence runs; and second, with the wheel stationary. No difference was found in the fluorescence emission as a result of this difference in excitation conditions. The phosphorescence spectra were examined at 4 milliseconds after cessation of excitation.

Four samples of $Zn_2SiO_4$:Mn, with Mn/Zn ratios of 0.0025, 0.01, 0.073, and 0.10, were studied. Three measurements were made of the phosphorescence spectrum of each sample and of its fluorescence spectrum. Confirming our earlier results and contradicting those of Nagy, none of the samples showed any significant difference between the spectra emitted in fluorescence and phosphorescence. The agreement between the various spectra of each phosphor was so close that a column-size figure is inadequate for presentation of the data. Typical data is accordingly given in tabular form (Table I) to illustrate the excellent reproducibility of the runs and the degree of agreement between the fluorescence and phosphorescence spectra.

In order to see if our radiometer was capable of detecting effects of the magnitude reported by Nagy, we simulated such a difference in emission spectra by blending 10 percent of Froelich's yellow-emitting $Zn_2SiO_4$:Mn [4] with 90 percent of the normal green-emitting willemite (Mn/Zn=0.01). The emission of the blend was found to be readily distinguishable from that of the willemite, the difference between the two spectra being approximately the same as that found by Nagy between the fluorescence and phosphorescence spectra of $Zn_2SiO_4$:Mn. It is believed, therefore, that our equipment is capable of detecting changes in spectral distribution of the magnitude found by Nagy.

The additional measurements reported here thus confirm our original conclusion of the invariance of the emission spectrum of $Zn_2SiO_4$:Mn with decay time. The reason for the discrepancy between Nagy's results and ours is not known. It would be highly desirable to have this work repeated by other laboratories so that a final decision could be reached.

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[4] H. C. Froelich, J. Phys. Chem. 47, 669 (1943).

## A Method of Determining Concurrently the Thickness and Refractive Index of a Thin Film or Lamina

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June 6, 1950

THE thickness is determined by an optical method, which does not require a knowledge of the refractive index, and is believed to be new.

White light emerging from a Michelson interferometer, set so that the optical path difference $D$, between the two beams is everywhere constant, enters the slit of a spectrometer, the mirrors and the slit being at conjugate distances from the collecting lens. The spectrum is channelled and the relationship between the order $m_1$ and the wave number $\nu$ of the dark bands is given by

$$m_1 = D\nu. \tag{1}$$

A film of thickness $t$, and refractive index $n$, introduced into the longer path alters this to

$$m_2 = \{D + 2(n-1)t\}\nu. \tag{2}$$

If, without any movement of the specimen, both mirrors are now covered, the channelled spectrum produced by multiple reflections within the film is described by

$$m_3 = 2nt\nu. \tag{3}$$

Observations are made on each of these three spectra and a graph of the order of each dark band (counted from an arbitrary zero) is plotted against its wave number.

From Eqs. (1), (2), and (3) at a wave number $\nu_1$

$$[m_3 - (m_2 - m_1)] = 2t\nu_1, \tag{4}$$

where the notation $[\cdots]$ denotes the value of a quantity at the wave number $\nu_1$. Differentiation gives

$$\left[\frac{dm_3}{d\nu} - \left(\frac{dm_2}{d\nu} - \frac{dm_1}{d\nu}\right)\right] = 2t. \tag{5}$$

Now $[m_1] \equiv [x_1 + \epsilon_1]$ where $x_1$ represents the integral, and $\epsilon_1$ the fractional part of $m_1$; similarly for $[m_2]$ and $[m_3]$. Therefore

$$[m_3 - (m_2 - m_1)] = \underbrace{[x_3 - (x_2 - x_1)]}_{\equiv [x]} + \underbrace{[\epsilon_3 - (\epsilon_2 - \epsilon_1)]}_{+[\epsilon]}. \tag{6}$$

From the slopes of the graphs, Eq. (5) gives an approximate value for $2t$, which, from Eq. (4) gives $[m_3 - (m_2 - m_1)]$ with sufficient accuracy to determine the integral part $[x]$ in Eq. (6). The fractional part $[\epsilon]$ is calculated from the individual values of $[\epsilon_1]$, $[\epsilon_2]$, and $[\epsilon_3]$ determined from the graphs. These experimentally found values of $[x]$ and $[\epsilon]$ give $[m_3 - (m_2 - m_1)]$ accurately, from which a more accurate value of $t$ is calculated using Eq. (4).

The interference bands represented by Eq. (3), have been used by several workers,[1-6] and various methods have been applied to obtain the dispersion curve of the specimen. The following modification requires the thickness of the specimen, as determined above, and is more positive in assigning the true order to each fringe.

Differentiation of Eq. (3) and multiplication by $\nu_1$ gives

$$\left[\frac{dm_3}{d\nu}\right]\nu_1 = 2nt\nu_1 + 2t\nu_1^2\left[\frac{dn}{d\nu}\right].$$
$$= [m_3']$$

Therefore, it is clear that the method of deducing the order directly from the slope of the graph, gives a value $[m_3']$, which is greater than the true value $[m_3]$, from Eq. (3) by the dispersion term $2t\nu_1^2[dn/d\nu]$. This value of $[m_3'] = [x_3' + \epsilon_3']$ is used to deduce the required value of $[m_3]$, as follows. The fractional part $[\epsilon_3]$ of $[m_3]$ is determined experimentally, hence a value for $[m_3]$ is given by $[x_3' + \epsilon_3]$, which will be in error by an integer $p$, if $2t\nu_1^2[dn/d\nu]$ is greater than 1. The same ambiguity $p$ also exists in the determination of $[m_2 - m_1]$; (this is also true of the standard method of finding $2(n-1)t$ by the combination of monochromatic and white light fringes). The ambiguity can be removed by making similar measurements on specimens of different thicknesses, since only the true values of $[m_3]$ will give the same refractive index. Alternatively, an approximate value of the index found from other methods with the necessary accuracy, can be used to assign the correct integral part $[x_3]$ to $[m_3]$. Because the points of observation are all of integral order, the true order of each fringe is then known, and the dispersion curve can be calculated from Eq. (3).

The interferometer is used only for the determination of thickness; once this is known the method of determining the order of a fringe may be applied to any region of the spectrum.

The method gave the thickness of a mica specimen as 12.19 $\pm 0.02\mu$, and one of its principal refractive indices as $1.601 \pm 0.003$ for sodium light. The errors quoted are provisional, and are not intended to represent the final limit of accuracy of the method. It is hoped to publish a fuller account later.

My thanks are due A. M. Taylor for many valuable discussions, and the Department of Scientific and Industrial Research for a research grant.

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## A Dividing Gear for a Ruling Engine

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June 6, 1950

IN recent months there has been much discussion of diffraction gratings and their manufacture. I would like to present a new idea for the design of a dividing gear for a ruling engine.

The design of this gear incorporates the idea of over-constraint with averaging which has been used in connection with the ruling carriage ways.[1] The gear that has this property is one incorporating the globoid design. In this gear the accuracy of spacing is not sustained by only one or a few teeth, as in the conventional design, but as in the case of my gear of 900 teeth, 75 of these teeth are in contact at all times, so that the property of over-constraint with averaging is realized.

The limit of the pinion thread length or face is determined by the base circle diameter which is established by the pressure angle (20° approx.). Within this length, which is approximately 30 degrees of the gear, all teeth contact the pinion simultaneously. The nature of the contact is such that, in the passage of the worm through the worm wheel, during one convolution, every portion of the worm thread and tooth flank is in contact. For a considerable distance above and below, and at the mid-plane of the worm wheel, the contact is continuous. The remaining portions are in periodic engagement. Furthermore, the elements regenerate or

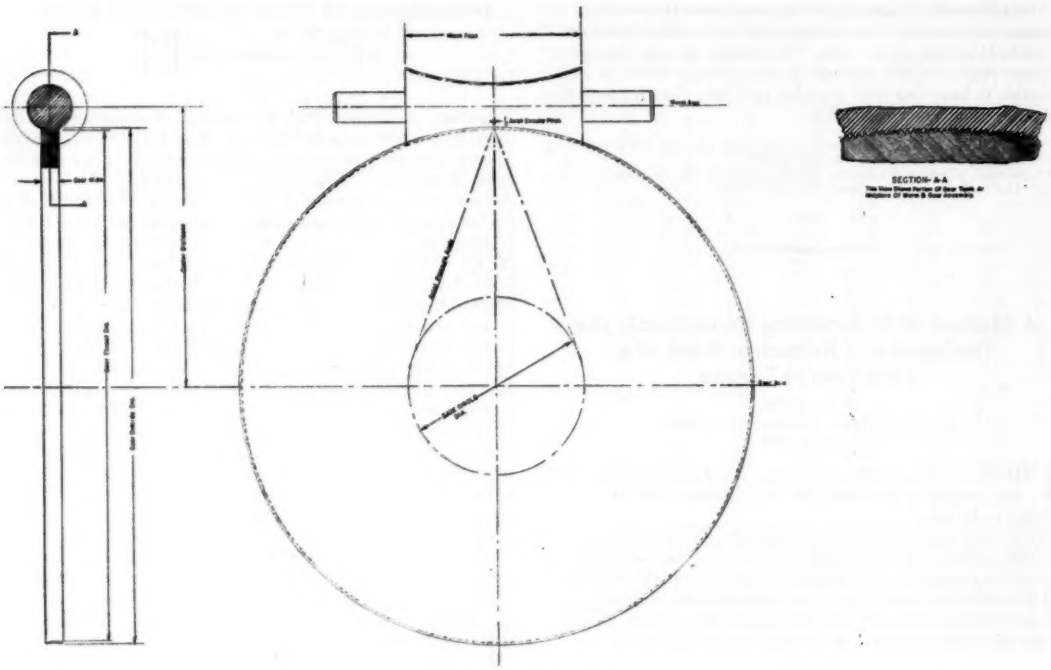

FIG. 1. Worm and gear.

reproduce themselves into the true theoretical form when the units are lapped together.

The gear set, because of its construction and tooth form, tends to force the oil through the mating faces, in a manner closely analogous to the conditions found in a Kingsbury type of bearing. Figure 1 is a drawing of the worm and gear.

[1] John Strong, ONR Report, November 11, 1948.

# News from the Local Sections of the Optical Society of America

## History of the Rochester Section

EARLY in 1950 the Optical Society of America Local Section News Letter initiated a series of feature articles on the histories of the several local sections. The Rochester Section was invited to be the first to contribute its history, in view of its very senior position in the local section framework. This created considerable interest on the part of the officers and members of the section, and it was decided to have the history reviewed in four installments at meetings of the section, each part being prepared and given by a member who was closely associated with the section's activities during the period involved. This necessitated a careful study of the executive council records and of the minutes of the many meetings that had been held. The first report was given by Leon V. Foster at the meeting held on January 24, 1950, and covered the period 1915–1924. On February 12, F. E. Altman discussed the period 1924–1932; on March 14, F. M. E. Holmes covered the years 1933–1941, and on April 11, Paul W. Stevens gave the final installment, which covered from 1941 to the present. Mr. Foster's sketch of the early years of the section was reproduced in Local Section News Letter No. 5, and Mr. Steven's collation of data on the years 1924–1950 was published in News Letter No. 6. These two contributions are combined below. They have been left substantially in the form in which they were submitted, even to retaining the more forceful use of the first person. The general preparation of this material for the News Letter has been under the direction of Mr. Stevens, who was Secretary of the Rochester Section during the year 1947–1948 and served as section scribe (contributor to the Local Section News Letter) for the two succeeding years.

It will be a matter of interest and perhaps surprise to many members of the Optical Society of America to learn that the national organization was in fact antedated by the local group which we now properly call the Rochester Section. As is set forth below, this group met independently during the winter of 1915–1916, and then initiated the steps which resulted in the formation of the national society from that nucleus.

STANLEY S. BALLARD
*Secretary for Local Sections*

The first written record of activities of the group now known as the Rochester Section of the Optical Society of America was made on November 18, 1915 by Dr. L. A. Jones, who was appointed temporary secretary of a gathering to discuss the general organization of an optical society for Rochester. Present at this meeting were P. G. Nutting, H. Kellner, F. E. Ross, H. Minchin, W. B. Rayton, L. A. Jones, C. H. Frederick, Adolph Lomb, and F. B. Saegmuller. Dr. Kellner was appointed temporary chairman. There were five names proposed for the society, and it was finally agreed that the name should either be "Association for the Advancement of Applied Optics," or "Society for the Advancement of Applied Optics." At this meeting the aims and purposes of the Society were formulated and recorded: "to promote the mutual interests of workers in applied optics and the manufacturers, designers, and users of optical instruments and appliances of all kinds." It was further agreed at this organization meeting that there should be six officers plus four additional members of the executive council, which would also include all the past presidents, and it was agreed that there should be three classes of membership: regular, associate, and corporation. The types of regular membership were to be ordinary, life, and honorary, and the dues were to be $50 for life members, $50 per year for corporation members, and $2 per year for all others. At this organization meeting it was agreed to hold meetings every first and third Tuesday of each month from October 1 to May 31, excepting holidays. Dr. Nutting was appointed Chairman to work with Mr. Lomb, Dr. Rayton, and Dr. Jones to draft a constitution and bylaws to present at the next meeting, which would be held November 23, only five days after the first organization meeting. At this time the constitution and bylaws were read and discussed in detail. The name of the society which was adopted at this meeting was "The Association for the Advancement of Applied Optics." It was then agreed to limit the charter membership to 15, and six more men were chosen to be invited to become charter members. On December 7, 1915, the constitution was approved and signed by 14 people, and the first officers elected were:

| | |
|---|---|
| President: | P. G. Nutting |
| Vice Presidents: | H. Kellner |
| | H. Minchin |
| Treasurer: | A. Lomb |
| Corresponding Secretary: | F. E. Ross |
| Recording Secretary: | L. A. Jones |
| Members-at-Large of the Executive Council: | E. J. Bissell |
| | W. B. Rayton |
| | C. W. Frederick |
| | F. B. Saegmuller |

The first regular meeting was held on January 4, 1916, with President Nutting speaking on "The Needs of Applied Optics." It was at a council meeting in February 1916 that plans relating to the organization of a national society were discussed, and President Nutting was authorized to communicate with a number of men throughout the country who would be interested in the formation of such an organization. At a council meeting the following month President Nutting announced the receipt of numerous letters from persons expressing interest in the formation of a national society. It was decided to send a copy of the proposed constitution and bylaws, with an invitation to become a charter member of a national organization, to about forty people prominent in various fields of applied optics.

During the first year of the local association ten regular meetings were held and the average attendance was approximately fifty. Regular meetings were held until the spring of 1918, when they were interrupted by World War I. The last meeting was the 36th general meeting, held in the Eastman Building of the University of Rochester on April 16, with only seven persons attending. Apparently no meetings of the local society were held again during the fall of 1918, or the spring of 1919. On October 21, 1919, a council meeting was held and it was agreed to resume meetings of the "Rochester Section of the Optical Society of America" once a month. The 37th general meeting was held on November 18, 1919, when Dr. L. A. Jones spoke on "Low Visibility and Its Uses as a Defensive Measure in Warfare." The records do not indicate exactly when the change of name of the organization took place.

In July 1920 the president of the local section was Dr. L. A. Jones. He appointed Dr. W. B. Rayton as the chairman of a committee to revise the constitution and bylaws. These were prepared during the summer of that year, and in October 1920 were presented and adopted. At this time the number of meetings was decided by the program committee. The roster of officers had by now shrunk to four (president, vice president, secretary, treasurer), plus a council which included four members and the most recent past president. The first printed program of the section was issued in the fall of 1922, and there were 14 meetings held in that society year.

During these first nine years of activities in Rochester, which

brings us to the spring of 1924, many men who later became prominent members of the national society and contributed greatly to its growth were invited to speak at the local society's meetings. A few of these are noted here: F. E. Wright, F. K. Richtmyer, James Southall, C. E. K. Mees, H. P. Gage, Irving Langmuir, R. W. Wood, L. T. Troland, E. D. Tillyer, L. A. Jones, and W. B. Rayton.

The activities of the Rochester Section have reflected its steady growth during the following twenty-six years, and the nature of its activities has remained essentially the same. Of major importance have been the semimonthly meetings from October through May, at which local and out-of-town scientists and engineers were invited to lecture on topics of current interest. The records indicate that in a number of cases speakers have been invited to return to address the section's meetings another time, and often the section has been privileged to hear previews or repeat performances of papers presented at meetings of the national society. Council meetings are held at intervals throughout the year, and matters of policy, nominations for membership, and other items of business are discussed and transacted.

The members of the Rochester Section have evinced interest in the national meetings of the Optical Society of America by playing host to those held in Rochester, but also through committee work, paper presentation, and attendance at meetings held elsewhere. Three meetings of the national society have been held in Rochester, and at almost ten-year intervals. The first was the Helmholtz Memorial Meeting of October 1921; Professor J. P. C. Southall of Columbia University was then President of the Society. One feature of this meeting which lingers in the memories of some of our senior members is the account by Professor Michael Pupin of Columbia of his experiences while studying under the great Helmholtz at the University of Berlin. The Society held its annual meeting of October 1931 in Rochester, with Dr. L. A. Jones in the presidential chair. The last meeting at which Rochester played host was that of October 1940, held under the presidency of Dr. K. S. Gibson of the National Bureau of Standards.

The annual program card which lists the dates, speakers, and titles of all meetings was first mailed to the membership in the 1922–1923 season. Eight years later a directory of members was added to this card, on which previously had been listed only the names of the officers and committee men. Preceding each person's name was printed a code letter indicating his professional connection. At that time, 1930, the list of members of the Rochester Section had grown to 118. In 1948, when this list had just passed the 400 mark, each major plant and the University of Rochester was listed separately with all members in each organization in alphabetical order.

It has always been the policy to encourage joint meetings, the interchange of official representatives, and other cooperative activities with local technical groups with allied interests, such as the Rochester Sections of the American Chemical Society and the Photographic Society of America, the Rochester Engineering Society, and the Rochester Academy of Science. One great advantage of these arrangements is that it makes possible securing as speakers distinguished foreign scientists such as Sir Lawrence Bragg and Sir Harold Spencer Jones of England, and Professor A. C. S. van Heel of Holland, who have addressed combined meetings within the last two years.

The growth and development of the Rochester Section was assisted by the foundation of the Institute of Optics at the University of Rochester in 1928. The Institute was partially financed in its early years by contributions from the Eastman Kodak Company and the Bausch and Lomb Optical Company, and the technical and junior scientific personnel of these and other local companies have benefited by the evening courses in optics and photography which have been a feature of the Institute's program. Many of the section meetings have been held in the Institute lecture rooms.

The dinner meetings form the section's major social activity. At first these were held only before those meetings at which the speaker was from out of town. As such, the dinner afforded an excellent opportunity for achieving a closer acquaintance with the speaker, or the renewal of old friendships. These dinners were so successful that in recent years it has become customary to hold them before all meetings; attendance varies from eight to twenty, with an average of about twelve. Each season concludes with an election of officers and an annual dinner to which the ladies are especially invited. Since 1939, attempts have been made to have the lecture following the annual dinner be of a popular nature of wide interest to the ladies and friends of the society. A notable example was the address given in 1947 by Vincent J. Schaefer, General Electric scientist of artificial rain fame, whose topic was "Scientific Fun in the Fields, the Mountains, and the Sky."

As the section membership grew and times changed, it was inevitable that the treasury balance should wax and wane, and that occasionally the section found itself with surplus funds. The first record of such an experience finds the council, at its meeting on May 12, 1936, considering means of disposition of the surplus, after retaining a reasonable reserve for leaner times. In very recent years contributions have been made to the national society to help defray the publication costs of the Local Section News Letter.

The advent of World War II brought to the Rochester Section the problems which confronted many a scientific society. On March 18, 1941, it was voted to suspend the assessment of dues upon any members who were called into military service by operation of the Selective Service Act, their membership to be continued automatically throughout the duration of such service. In the fall of 1942 the place of meeting reverted from the River Campus of the University to the Prince Street Campus; the more central location of the Prince Street buildings was favored during a period of increased transportation difficulties. The meeting of November 28, 1944 was the first one to be held in the new Museum of Arts and Sciences on East Avenue. It is now quite generally agreed that the Museum forms the ideal meeting place, except when lectures require the use of demonstration apparatus in optics such as is readily at hand in the Institute of Optics.

A noteworthy service of the section during the closing years of the war was an active campaign to collect scientific and professional periodicals to replace the damaged copies in European libraries. Harold R. Bennett proved a capable chairman in this endeavor, which was carried on in cooperation with the American Institute of Physics and the American Library Association.

The beginning of a new decade finds the Rochester Section looking forward with enthusiasm to a period of even greater progress, and one of continuing cooperation with the Optical Society: both the national organization and its local sections. Lecture tours and visitations among the sections are eagerly sought, and our members are always glad to renew acquaintances and compare notes with members of other sections at the national meetings.